Compliance with Global 24-Hour Movement Behaviours in 3–4 Year-Olds: A Low-Income Sub-Saharan African Country Perspective

Tawonga Welson Kazgakawo Mwase-Vuma

Department of Psychological Sciences and Health

Faculty of Humanities and Social Sciences

University of Strathclyde

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Declaration

Signed:

Date: 19/08/2025

Tawonga Welson Kazgakawo Mwase-Vuma

August 2025

Declaration of contribution to thesis

All data used in studies that comprise the body of work in this thesis were based on an established international collaborative research project, the SUNRISE International Study. However, in all of the studies presented in this thesis, the majority of the work is directly attributable to the PhD student under the supervision of Professor John J. Reilly and Dr Xanne Janssen. I led the work presented in this thesis, including local ethics application, recruitment and primary data collection in Malawi, conducted all statistical analyses, including processing ActiGraph accelerometry data from Malawi, and drafted manuscripts for publication in peer-reviewed international journals. My supervisory team obtained funding, advised on study design and statistical analyses, and provided feedback on all written work presented in this thesis.

The work presented in this thesis also benefited from the supervisory support and the SUNRISE International Study collaborations that were vital to the success of the project. Notably, my supervisors obtained funding for the work presented in this thesis and were involved in the formulation of research ideas. The SUNRISE Coordinating Centre provided data for the two secondary analysis studies and equipment for primary data collection in Malawi, as well as supported cleaning and management of the Malawi study data. All authors for the published and submitted work, where listed, contributed to data acquisition, provided critical inputs to draft manuscripts, and approved final versions. The relevant contributions for each author to the published work presented in this thesis is acknowledged in the respective chapter.

Tawonga Welson Kazgakawo Mwase-Vuma

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Abstract

Malawi, like other low-income sub-Saharan African (SSA) countries, is experiencing economic transition that may result in lifestyle changes, such as physical inactivity, increased sedentary behaviours, and poor nutrition. This shift may further increase the burden of movement behaviour-related non-communicable diseases (NCDs) and obesity in the country and globally. The 2019 global 24-hour movement behaviour guidelines for the under 5s were published to promote children's healthy growth and development and to tackle NCDs and obesity globally. Despite publication over five years ago, there is limited evidence of compliance from low- and middle-income countries, particularly in SSA. Additionally, no studies have assessed feasible measurement methods for large-scale surveillance globally.

Guided by the Behavioural Epidemiology Framework, this thesis provides novel evidence in the field of 24-hour movement behaviours in early childhood. Parent reports and daily step counts were validated against accelerometry for assessing total physical activity (TPA) in 3–4 year olds globally (Chapter 3). The step count threshold of 11,500 steps/day, equivalent to 180 minutes/day of TPA, provided valid measures but parent reports did not. This threshold was then used in cross-sectional studies to examine the prevalence and correlates of meeting the global guidelines (Chapters 4 and 5).

Chapter 4 revealed that only 31% of 3–4 year olds from diverse backgrounds met the TPA guideline based on step counting, and compliance was influenced by sex, age, residence (urban/rural), and country income. Chapter 5, focused on Malawi, revealed relatively high prevalence (60%) of meeting all four 24-hour movement guidelines (physical activity, restrained sitting, screen time, sleep duration) among 3–4 year olds. Meeting guidelines was predominantly influenced by residential setting (23% urban versus 70% rural), suggesting that physical activity transition maybe underway particularly in urban areas.

This thesis provides evidence to inform practical surveillance systems for monitoring movement behaviours among young children in resource-limited settings and can help develop tailored interventions to sustain healthy lifestyles during ongoing economic transformations, delay the physical activity transition, and reduce NCDs in Malawi and similar contexts.

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Firstly, I would like to express my sincere gratitude to my supervisors, Professor John J. Reilly and Dr Xanne Janssen. Thank you for your time, knowledge, guidance, and support, and for introducing me to movement behaviour research, which I am now passionate about. Your exceptional understanding, inspiration, and support throughout my study period, including during the COVID-19 pandemic, motivated me to persevere.

A special thanks to my primary supervisor, John, for introducing me to the SUNRISE International Study, which formed the foundation of my PhD research and opened numerous networking and collaboration opportunities. Thank you for instilling confidence in my abilities and maintaining a positive attitude, which greatly inspired me throughout my studies. To everyone in the Physical Activity and Health research group at the University of Strathclyde, thank you. I felt welcomed and experienced the true PhD life during my short stays in Glasgow, especially as my study was largely remote and isolated.

I am also grateful to the SUNRISE Coordinating Centre staff at the University of Wollongong and the Chief Investigators from participating countries for their valuable contributions to the research presented in this thesis. A special thanks to the SUNRISE Malawi research team – Janine, Seth, Kate, and Tobias. I am very grateful for your moral support and contributions throughout the data collection period Malawi. Thanks to all study participants who generously offered their time to engage in the studies that comprise the body of work in this thesis.

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List of Papers and Conference Presentations

During my PhD study within the Department of Psychological Sciences and Health at the University of Strathclyde, the following papers were published and comprised the body of work in this thesis.

Chapter 3

1. **Mwase-Vuma TW**, Janssen X, Okely AD, et al. Validity of low-cost measures for global surveillance of physical activity in pre-school children: The SUNRISE validation study. *J Sci Med Sport*. 2022;25(12):1002-1007. doi:10.1016/j.jsams.2022.10.003

Chapter 4

2. **Mwase-Vuma TW**, Janssen X, Chong KH, et al. Prevalence and correlates of adherence to the global total physical activity guideline based on step counting among 3- to 4-year-olds: Evidence from SUNRISE pilot studies from 17 countries. *J Phys Act Heal*. 2024;21(8):794-801. doi:10.1123/jpah.2023-0711

In addition, the body of work in this thesis comprise the following submitted manuscript currently under review.

Chapter 5

3. **Mwase-Vuma TW**, Janssen X, Okely AD, Kayange J, Chong KH, Cross P, Evance S, & Reilly JJ. Prevalence and correlates of meeting World Health Organization 24-hour movement guidelines among 3–4-year-olds in Malawi: The cross-sectional SUNRISE Malawi Study. *J Phys Act Heal*. (Under Review).

During the same period, I presented the following papers/abstracts at local and international conferences, including in Malawi where primary data collection was conducted (Chapter 5).

1. **Mwase-Vuma TW,** Janssen X, Evance S, Okely AD, Kayange J, Chong KH, Cross P, Reilly JJ. Compliance with the global 24-hour movement guidelines among pre-schoolers in Malawi: The SUNRISE Malawi Study. *The 10th International Society for Physical Activity and Health (ISPAH) Congress.* 28th to 31st October 2024, Paris, France. [Chapter 5]

2. **Mwase-Vuma TW,** Janssen X, Evance S, Okely AD, Kayange J, Chong KH, Cross P, Reilly JJ. Examining the prevalence and correlates of meeting the global 24-hour movement guidelines among young children in a low-income African setting: The SUNRISE Malawi Study. *The Society for the Study of Human Biology (SSHB) Conference.* 11th to 13th September 2024, Porto, Portugal. [Chapter 5]

3. **Mwase-Vuma TW,** Janssen X, Evance S, Okely AD, Kayange J, Chong KH, Cross P, Reilly JJ. Prevalence and correlates of meeting the global physical activity, sedentary behaviours, and sleep guidelines among 3-4-year-old children in Malawi: The SUNRISE Malawi Study. *The 2nd KUHeS Research Dissemination Conference.* 30th November to 1st December 2023. Blantyre, Malawi. [Chapter 5]

4. **Mwase-Vuma TW,** Janssen X, Chong KH, Okely AD, … Reilly JJ. Examining the prevalence and sociodemographic correlates of meeting the WHO total physical activity guideline based on step-counts among young children: The SUNRISE Study. *The 8th Scottish Physical Activity Research Connections (SPARC).* 8th November 2023, Edinburgh, Scotland. [Chapter 4]

5. **Mwase-Vuma TW,** Janssen X, Okely AD, Tremblay, MS, … Reilly JJ. Validity of step-counting for global surveillance of physical activity in pre-schoolers: the SUNRISE Validation Study. *The 9th ISPAH Congress.* 23rd to 26th October 2022, Abu Dhabi, United Arab Emirates. [Chapter 3]

6. Kayange JJ**,** Munthali AC, Okely, AD, Reilly JJ, Chunga JJ, Harawa K, Evance S, Janssen X, & **Mwase-Vuma TW**. Practical considerations for pre-school-based physical activity research in low-income settings: The SUNRISE Malawi pilot study. *The 9th ISPAH Congress.* 23rd to 26th October 2022, Abu Dhabi, United Arab Emirates. [Chapter 5]

7. **Mwase-Vuma TW,** Janssen X, Chong KH, Okely AD, […] Reilly JJ. Prevalence and correlates of adherence to total physical activity guidelines using step-counting in pre-school children: the SUNRISE study. *The International Festival of Sports, Exercise & Medicine Conference.* 29th September to 2nd October 2023, Pretoria, South Africa. [Chapter 4]

8. **Mwase-Vuma TW,** Janssen X, Okely AD, Tremblay, MS, … Reilly JJ. Validation of low-cost measurement tools for assessing habitual physical activity in pre-schoolers: The SUNRISE study. *The 8th International Conference on Ambulatory Monitoring of Physical Activity and Movement (ICAMPAM).* 21st to 24th June 2022, Keystone, Colorado, USA. [Chapter 3]

9. **Mwase-Vuma TW,** Janssen X, Okely AD, Tremblay, MS, … Reilly JJ. Validity of step-counting for global monitoring of physical activity among pre-school children. *Doctoral School Multidisciplinary Symposium (DSMS).* 8th to 10th June 2022, University of Strathclyde, Glasgow, Scotland. [Chapter 3]

10. **Mwase-Vuma TW**, Janssen X, Reilly JJ. Validity of parent-reported level of physical activity among preschool children against accelerometry in 13 countries: evidence from

the SUNRISE study. *Children's physical activity – a research area more crucial than ever!* 25th August 2021, Odense, Denmark. [Chapter 3]

Table of contents

List of figures

List of tables

List of abbreviations

AHKGA-GM	Healthy Kids Global Alliance Global Matrix
AIDS	Acquired immunodeficiency syndrome
AOR	Adjusted odds ratio
AUC	Area under the ROC curve
BMI	Body mass index
CARS	Children's Activity Rating Scale
CHW	Community health worker
CI	Confidence interval
CIHR	Canadian Institutes of Health Research
COVID-19	Coronavirus disease 2019
DALY	Disability adjusted life years
ECD	Early childhood development
ECE	Early childhood education
ECEC	Early childhood education and care
ECHO	Commission on Ending Childhood Obesity
GDP	Growth domestic product
GRADE	Grading of Recommendations Assessment, Development and Evaluation
HBSC	Health Behaviour in School-aged Children
HDI	Human Development Index
HIC	High-income country
HIV	Human immunodeficiency virus
ICAD	International Children’s Accelerometry Database
ICC	Interclass coefficients
ISPF	International Science Partnerships Fund
LIC	Low-income country
LMIC	Low- and middle-income country
LMVPA	Light-moderate-vigorous-intensity physical activity
MAR	Missing at random
MCAR	Missing completely at random
MET	Metabolic equivalent
MIC	Middle-income country
MNAR	Missing not at random
MPA	Moderate physical activity
MVPA	Moderate-to-vigorous intensity physical activity

NCD	Non-communicable diseases
NGO	Non-governmental organisations
OR	Odds ratio
PA	Physical activity
RCT	Randomised controlled trial
REDCap	Research Electronic Data Capture
ROC	Receiver operating characteristic curve
SB	Sedentary behaviour
SES	Socioeconomic status
SFC	Scottish Funding Council
SDG	Sustainable development goal
SSA	Sub-Saharan Africa
ST	Screen time
STEPS	STEPwise approach to NCD risk factor surveillance
SUNRISE	International Study of Movement Behaviours in the Early Years
TPA	Total physical activity
TV	Television
USD	United States dollar
UOW	University of Wollongong
WHO	World Health Organization

Chapter 1: Introduction

1.1 Background and context

Non-communicable diseases (NCDs), particularly cardiovascular diseases, chronic respiratory diseases, cancer, and diabetes, continue to be among the leading causes of deaths globally.[1] The burden of NCDs is disproportionately higher in low- and middle-income countries (LMICs), with an estimated 77% of all NCD related deaths occurring in these countries.[2] Malawi, like many other low-income countries, is experiencing an increasing burden of NCDs alongside existing communicable diseases.[3,4] In 2019, NCDs accounted for 43% of deaths in Malawi.[5]

The World Health Organization (WHO) identifies overweight/obesity and physical inactivity among the risk factors for NCDs.[2] The ongoing socioeconomic development and urbanisation occurring in many LMICs globally, including Malawi,[6] may inevitably result in lifestyle changes (such as physical inactivity, prolonged sedentary behaviours, unhealthy dietary patterns) leading to increased risk of NCDs and obesity.[7,8] Understanding the risk factors and population groups at increased risk of NCDs and obesity is one of the critical steps for the prevention and control of NCDs.[3] Thus, preventing and controlling NCDs in LMICs will be essential for ensuring good health and wellbeing globally, as expounded in the United Nations 2030 Agenda for Sustainable Development.[9]

Evidence has shown that NCDs and obesity related risk factors have their origins during early childhood.[10–12] Recognising the importance of early childhood on future health and the need for tackling the global obesity pandemic and related NCDs, the WHO in April 2019 published the first ever global guidelines on movement behaviours (physical activity, sedentary behaviour, and sleep) for children below the age of five.[13] While studies have focused on assessing compliance with individual behaviour guidelines, particularly physical activity,[14,15] the optimal combination of these behaviours is crucial for healthy growth and development in early childhood.[13] Thus, the holistic approach to understanding these childhood movement behaviours is crucial to acknowledge the co-dependency of the behaviours.[14,16–19]

When effectively promoted, healthy movement behaviours (i.e., increased physical activity, reduced sedentary screen time, and adequate quantity of sleep) in young children would contribute towards the global target of a 15% reduction in the prevalence of insufficient physical activity by 2030.[20] Despite the publication of the global 24-hour movement behaviour guidelines over five years ago[13] and ongoing efforts to reach the 2030 physical activity target globally,[21] there remains relatively limited evidence on compliance with the global movement behaviour guidelines among young children from many LMICs,[22,23] particularly in sub-Saharan Africa (SSA).[24]

At the time the research work in this thesis started in 2020, there was almost no evidence on the prevalence of meeting the global movement behaviours guidelines and understanding of their correlates among 3–4 year olds in low- and middle-income SSA context. A 2020 systematic review by Nusurupia et al.[24] found only two small pilot studies from SSA that had measured time spent in the movement behaviours. Since then, the *SUNRISE International Study of Movement Behaviours in the Early Years* (https://sunrise-study.com) has been developed and expanded to address this dearth of evidence,[25] progressing from pilot studies to main studies since its establishment in 2018. The SUNRISE International Study aims to collect data on movement behaviours (physical activity, sedentary behaviour, and sleep) in 3–4 year olds globally. A detailed description of the SUNRISE International Study is provided in the next chapter of this thesis (Chapter 2 *Section 2.5.1*). It is worth noting that while unhealthy dietary patterns are critical risk factors for NCDs and obesity as mentioned above and were collected as part of the SUNRISE International Study in Malawi (described in detail in Chapter 5),[25] analysis of dietary behaviours is beyond the scope of this thesis, which focuses specifically on 24-hour movement behaviours, and therefore warrants a separate detailed investigation.

In 2020 when the research work in this thesis began, there were 41 countries that were participating in the SUNRISE International Study. Participating countries implemented the SUNRISE International Study protocol[25] in two phases: a pilot study with a sample of 100 children to assess the acceptability and feasibility of the study protocol and the main study with a sample of 1000 children. The number of countries participating has grown to over 60 in 2024 at the time of writing this thesis.

The expansion of the SUNRISE International Study over the years has contributed to growing evidence on compliance with the global movement behaviour guidelines in early childhood globally, including in LMICs. However, to date, there have only been four studies that reported evidence of compliance with the global guidelines among young children in SSA settings,[26–29] with limited representation from low-income countries (LICs). The two pilot studies identified in a 2020 systematic review were both conducted in South Africa,[24] which is classified as a middle-income country (MIC) by the World Bank.[30] The Abdeta et al.[26] study among Ethiopian 3–4 year olds is somewhere between the pilot and main study (n=430), and the country is classified as low-income based on the World Bank classification.[30] While Chong et al.[29] pooled data from both SUNRISE and non-SUNRISE sources from 33 widely diverse countries globally, including low-, middle-, and high-income countries, to provide broader insights.

The measurement of movement behaviours in young children presents significant challenges, particularly in low-resource settings. Yet, no studies looked at the feasibility of measurements for large scale surveillance in LICs and SSA contexts. The two recent studies that included low-income SSA countries[26,29] assessed physical activity using accelerometry-measured activity counts (i.e., activity duration and intensity) which may have limited use in surveillance studies particularly in LICs due to the cost of devices and complexity of the measurement methods.[16,31–35] Movement behaviour research is a relatively new field, and the capacity gap in this field has been identified as a major barrier for effective surveillance in children and adolescents in LMICs.[15] Therefore, there is an urgent need for empirical evidence based on a larger sample that assessed compliance using feasible and culturally appropriate low-cost methods in low-income SSA settings to inform national surveillance systems.

Furthermore, understanding the correlates of healthy behaviours is essential for developing effective health promotion interventions in line with the Behavioural Epidemiology Framework (*Figure 1-1*).[36] The framework encapsulates the belief that valid measurement methods, prevalence data, and correlate data underpin rational development of evidence-based behavioural change interventions.[36] This research is required to identify correlates of compliance with the global 24-hour movement behaviour guidelines among young children in LICs and SSA. Previous studies suggest that sex, age, socioeconomic status, parental education, urbanicity, and environmental factors may influence meeting these global guidelines among young children,[22,23,37] with limited evidence from LMICs particularly in the SSA context as earlier noted. Understanding these correlates is essential for identifying (sub-)population groups (at risk of) not meeting the global guidelines and developing targeted interventions to promote health movement behaviours and improve childhood health and development. This is especially important in low-income SSA countries, including Malawi, where ongoing trends in economic development and urbanisation may lead to lifestyle changes and a shift in physical activity behaviours known as 'physical activity transition'.[38]

To address the above mentioned gaps in the literature, the body of work in this thesis examined the validity of low-cost movement behaviour measures and the prevalence and correlates of meeting the movement behaviour guidelines among Malawian 3–4 year olds. This evidence can help to inform the development of reliable national surveillance systems[20] that will be essential for monitoring healthy behavioural changes among young children during Malawi's socioeconomic transformations.[6] Furthermore, based on the Behavioural Epidemiology Framework,[36] understanding of the prevalence and correlates of meeting the global movement behaviour guidelines can help identify high risk groups and inform the development of more effective, targeted interventions to promote healthier movement behaviours among Malawian young children. This is particularly important given that compliance with the global guidelines may differ by country income group,[29] highlighting the importance of contextually appropriate evidence to inform policy interventions to promote healthy movement behaviours and reduce the risk factors for NCDs and obesity. The findings from this research can potentially be generalised to other low-income SSA countries that are also experiencing an increased burden of NCDs as well as undergoing socioeconomic development and rapid urbanisation.

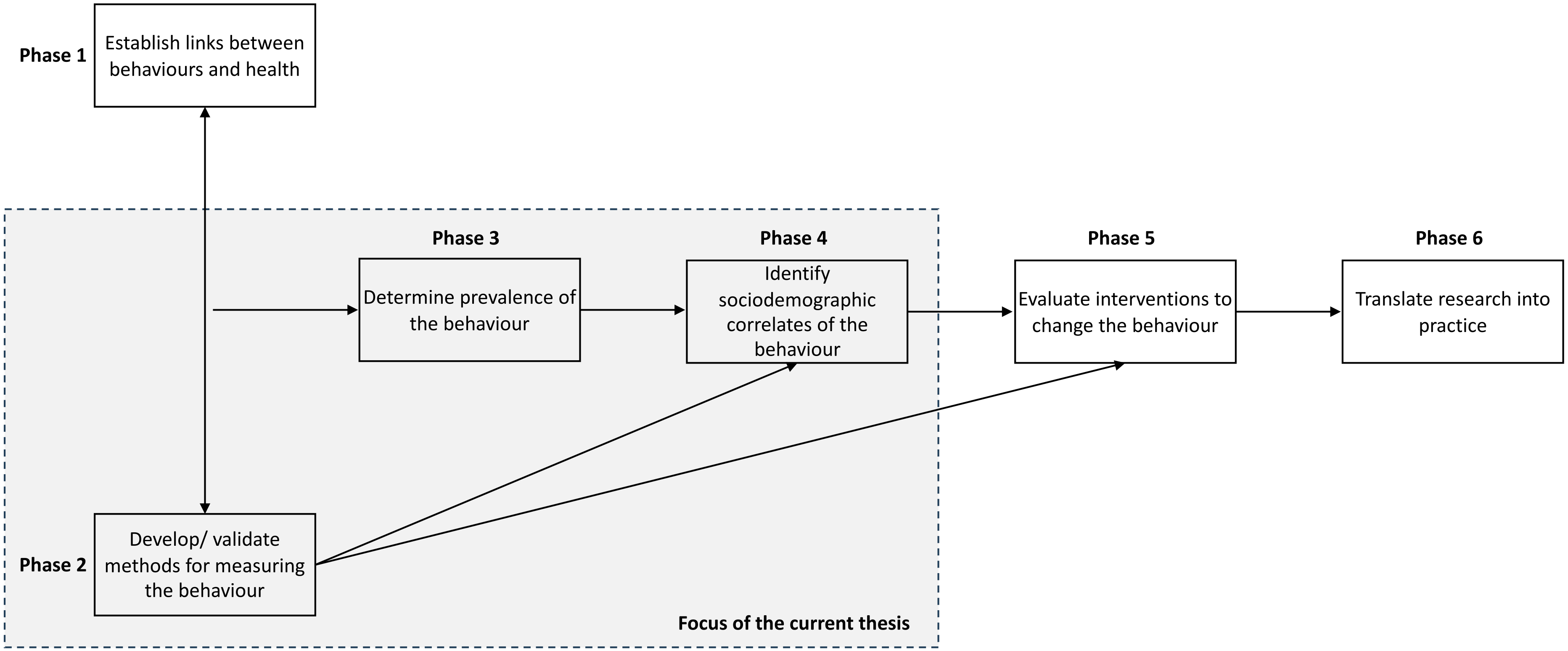

Figure 1-1: The Behavioural Epidemiology Framework. Adapted from Sallis et al. (2000)[36] and Carson et al. (2024)[16] The aims of the current thesis will focus on phases 2, 3, and 4 in order to inform healthy behavioural change interventions (Phase 5). ↔ denotes reciprocal connection; → denotes next phase

1.2 Thesis aims, research questions, and objectives

1.2.1 Aims

- To establish the culturally appropriateness and accuracy of low-cost measurement methods for assessing habitual total physical activity (TPA) among 3–4 year olds from vastly diverse backgrounds globally, including LMICs.
- To determine the prevalence and correlates of meeting the global TPA guideline based on step-counting among 3–4 year olds from vastly diverse backgrounds globally, including low- and middle-income SSA settings.
- To determine the prevalence and identify correlates of meeting the global 24-hour movement behaviour guidelines among 3–4 year-olds from a low-income SSA setting.

1.2.2 Research questions and objectives

This thesis will address three research questions and five objectives. These are outlined below along the corresponding thesis chapters.

Chapter 3	*Research question 1:* Are existing measurement methods valid and appropriate for assessing physical activity in young children from diverse backgrounds globally, including in LMICs? *Objective 1:* To validate low-cost measures (parent-reports and step-counts) for assessing habitual TPA in 3–4 year olds from 13 culturally and geographically diverse countries.
Chapter 4	*Research question 2:* What are the levels and correlates of compliance with the global TPA guideline based on low-cost, valid measurement method (identified in *Chapter 3*) among 3–4 year-olds from widely diverse backgrounds globally? *Objective 1:* To examine the prevalence of meeting the global TPA guideline based on daily step-counts in 3–4 year olds from 17 middle- and high-income countries. *Objective 2:* To examine the sociodemographic correlates of meeting the TPA guideline based on daily step-counts in 3–4 year olds from 17 middle- and high-income countries.
Chapter 5	*Research question 3:* What are the levels and correlates of compliance with the global 24-hour movement behaviour guidelines among Malawian 3–4 year-olds?

Objective 1: To examine the prevalence of meeting the global 24-hour movement behaviour guidelines among Malawian 3–4 year-olds.

Objective 2: To examine the sociodemographic correlates of meeting the global 24-hour movement behaviour guidelines among Malawian 3–4 year-olds.

1.3 Thesis structure

This thesis comprises three studies presented in three chapters (Chapters 3, 4, and 5): two chapters (Chapters 3 and 4) have been published in international peer-reviewed scientific journals, while Chapter 5 was submitted for publication and is currently under review. Before presenting the three studies, the next chapter (Chapter 2) provides a general literature review for the body of work presented in this thesis. This chapter first discusses the literature on movement behaviour related NCDs and associated childhood obesity, followed by a section on the global 24-hour movement behaviour guidelines in the early years, including the prevalence and correlates of meeting the guidelines in 3–4 year olds, then an overview of the SUNRISE International Study, and finally concludes with summarising research gaps in the literature.

The next three chapters (Chapters 3, 4, and 5) present the independent studies. Each chapter begins with a preface section followed by a section presenting the manuscript of the PhD study. The preface section provides a general overview of the chapter, a (detailed) description of the methodology to expand on the methods section of the published studies (Chapters 3 and 4) and submitted manuscript (Chapter 5), and chapter significance and contribution to research. The three chapters have been written for publication following the respective journal's formatting and structure requirements, and the articles have been presented in their published and submitted formats. Chapter 3 has been peer reviewed and published in the Journal of Science and Medicine in Sports and was highlighted in the journal's editorial.[39] Chapter 4 has been peer reviewed and published in the Journal of Physical Activity and Health. Chapter 5 comprise a manuscript that was developed and submitted for publication in the Journal of Physical Activity and Health.

Finally, Chapter 6 provides a general discussion of key findings from the three studies in relation to the wider context of the PhD thesis. The chapter also discusses the implications of the research work to policy and practice, the strengths and limitations, and concludes with directions for future research and conclusions.

1.4 Chapter References

1. Naghavi M, Ong KL, Aali A, et al. Global burden of 288 causes of death and life expectancy decomposition in 204 countries and territories and 811 subnational locations, 1990–2021: a systematic analysis for the Global Burden of Disease Study 2021. *The Lancet*. 2024;403(10440):2100-2132. doi:10.1016/S0140-6736(24)00367-2

2. World Health Organization. Non-communicable diseases. Fact Sheet. 2023. Accessed July 17, 2024. https://www.who.int/en/news-room/fact-sheets/detail/noncommunicable-diseases

3. Msyamboza KP, Ngwira B, Dzowela T, et al. The Burden of Selected Chronic Non-Communicable Diseases and Their Risk Factors in Malawi: Nationwide STEPS Survey. Su Z, ed. *PLoS One*. 2011;6(5):e20316. doi:10.1371/journal.pone.0020316

4. Gowshall M, Taylor-Robinson SD. The increasing prevalence of non-communicable diseases in low-middle income countries: The view from Malawi. *Int J Gen Med*. 2018;11:255-264. doi:10.2147/IJGM.S157987

5. World Health Organization. *Country Disease Outlook: Malawi*.; 2023. https://www.afro.who.int/sites/default/files/2023-08/Malawi.pdf

6. Government of Malawi. *Malawi's Vision: An Inclusively Wealthy and Self-Reliant Nation*.; 2020. Accessed March 3, 2024. https://npc.mw/wp-content/uploads/2021/02/MW2063-VISION-FINAL.pdf

7. Jaacks LM, Vandevijvere S, Pan A, et al. The obesity transition: stages of the global epidemic. *Lancet Diabetes Endocrinol*. 2019;7(3):231-240. doi:10.1016/S2213-8587(19)30026-9

8. Lange S, Vollmer S. The effect of economic development on population health: A review of the empirical evidence. *Br Med Bull*. 2017;121(1):47-60. doi:10.1093/bmb/ldw052

9. United Nations. *Transforming Our World: The 2030 Agenda for Sustainable Development*.; 2015. https://sustainabledevelopment.un.org/content/documents/21252030 Agenda for Sustainable Development web.pdf

10. Balbus JM, Barouki R, Birnbaum LS, et al. Early-life prevention of non-communicable diseases. *The Lancet*. 2013;381(9860):3-4. doi:10.1016/S0140-6736(12)61609-2

11. NCD Child. *Children & Non-Communicable Disease: Global Burden Report 2019*.; 2019. Accessed November 20, 2024. https://www.ncdchild.org/2019/01/28/children-non-communicable-disease-global-burden-report-2019/

12. Simmonds M, Llewellyn A, Owen CG, Woolacott N. Predicting adult obesity from childhood obesity: A systematic review and meta-analysis. *Obesity Reviews*. 2016;17(2):95-107. doi:10.1111/obr.12334

13. World Health Organization. *World Health Organisation Guidelines for Physical Activity, Sedentary Behaviour, and Sleep for Children under 5 Years of Age*.; 2019. Accessed March 13, 2024. https://www.who.int/publications/i/item/9789241550536

14. Okely A, Tremblay M, Reilly J, Draper C, Bull F. Physical activity, sedentary behaviour, and sleep: movement behaviours in early life. *Lancet Child Adolesc Health*. 2018;2:233-235.

15. Reilly JJ, Aubert S, Brazo-Sayavera J, Liu Y, Cagas JY, Tremblay MS. Surveillance to improve physical activity of children and adolescents. *Bull World Health Organ*. 2022;100(12):815-824. doi:10.2471/BLT.22.288569

16. Carson V, Draper CE, Okely A, Reilly JJ, Tremblay MS. Future Directions for Movement Behavior Research in the Early Years. *J Phys Act Health*. 2024;21(3):218-221. doi:10.1123/jpah.2023-0679

17. Chaput JP, Carson V, Gray CE, Tremblay MS. Importance of all movement behaviors in a 24 hour period for overall health. *Int J Environ Res Public Health*. 2014;11(12):12575-12581. doi:10.3390/ijerph111212575

18. Dumuid D, Olds T, Sawyer SM. Moving beyond more: towards a healthy balance of daily behaviours. *The Lancet*. 2021;398(10298):373-374. doi:10.1016/S0140-6736(21)01600-7

19. Rollo S, Antsygina O, Tremblay MS. The whole day matters: Understanding 24-hour movement guideline adherence and relationships with health indicators across the lifespan. *J Sport Health Sci*. 2020;9(6):493-510. doi:10.1016/j.jshs.2020.07.004

20. World Health Organization. *Global Action Plan on Physical Activity 2018–2030: More Active People for a Healthier World*.; 2018. https://www.who.int/publications/i/item/9789241514187

21. World Health Organization. *Global Status Report on Physical Activity 2022*.; 2022. https://www.who.int/teams/health-promotion/physical-activity/global-status-report-on-physical-activity-2022

22. Arts J, Drotos E, Singh AS, Chinapaw MJM, Altenburg TM, Gubbels JS. Correlates of Physical Activity in 0- to 5-year-olds: A Systematic Umbrella Review and Consultation of International Researchers. *Sports Medicine*. 2023;53(1):215-240. doi:10.1007/s40279-022-01761-5

23. Tapia-Serrano MA, Sevil-Serrano J, Sánchez-Miguel PA, López-Gil JF, Tremblay MS, García-Hermoso A. Prevalence of meeting 24-hour movement guidelines from pre-school to adolescence: A systematic review and meta-analysis including 387,437 participants and 23 countries. *J Sport Health Sci*. 2022;11(4):427-437. doi:10.1016/j.jshs.2022.01.005

24. Nusurupia J, J. RJ, Xanne J. Pre-school children's compliance with the WHO 24-hour movement behaviour guidelines: a systematic review of Sub-Saharan African studies. *African Journal for Physical Activity and Health Sciences (AJPHES)*. 2020;26(4):345-359. doi:10.10520/ejc-ajpherd1-v26-n4-a2

25. Okely AD, Reilly JJ, Tremblay MS, et al. Cross-sectional examination of 24-hour movement behaviours among 3- and 4-year-old children in urban and rural settings in low-income, middle-income and high-income countries: the SUNRISE study protocol. *BMJ Open*. 2021;11(10):e049267. doi:10.1136/bmjopen-2021-049267

26. Abdeta C, Cliff D, Kariippanon K, et al. Adherence to the WHO physical activity, screen time and sleep guidelines and associations with socio-demographic factors among Ethiopian preschool children: The SUNRISE study. *Journal of Activity, Sedentary and Sleep Behaviors*. 2024;3(1):22. doi:10.1186/s44167-024-00060-w

27. Draper C, Tomaz S, Cook C, et al. Understanding the influence of 24-hour movement behaviours on the health and development of preschool children from low-income South African settings: the SUNRISE pilot study. *South African Journal of Sports Medicine*. 2020;32:1-7. doi:10.17159/2078-516X/2020/v32i1a8415

28. Munambah N, Gretschel P, Muchirahondo F, et al. 24 hour movement behaviours and the health and development of pre-school children from Zimbabwean settings: The SUNRISE pilot study. *South African Journal of Sports Medicine*. 2021;33(1):1-9. doi:10.17159/2078-516X/2021/v33i1a10864

29. Chong KH, Suesse T, Cross PL, et al. Pooled Analysis of Physical Activity, Sedentary Behavior, and Sleep Among Children From 33 Countries. *JAMA Pediatr*. 2024;178(11):1199. doi:10.1001/jamapediatrics.2024.3330

30. The World Bank. World Bank country and lending groups. Accessed December 12, 2024. https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups

31. Adamo KB, Prince SA, Tricco AC, Connor-Gorber S, Tremblay M. A comparison of indirect versus direct measures for assessing physical activity in the pediatric population: A systematic review. *International Journal of Pediatric Obesity*. 2009;4(1):2-27. doi:10.1080/17477160802315010

32. Cardon G, De Bourdeaudhuij I. Comparison of Pedometer and Accelerometer Measures of Physical Activity in Preschool Children. *Pediatr Exerc Sci*. 2007;19:205-214. doi:https://doi-org.proxy.lib.strath.ac.uk/10.1123/pes.19.2.205

33. Oliver M, Schofield GM, Kolt GS. Physical Activity in Preschoolers: Understanding Prevalence and Measurement Issues. *Sports Medicine*. 2007;37(12):1045-1070. doi:10.2165/00007256-200737120-00004

34. Oliver M, Schofield GM, Kolt GS, Schluter PJ. Pedometer accuracy in physical activity assessment of preschool children. *J Sci Med Sport*. 2007;10(5):303-310. doi:10.1016/j.jsams.2006.07.004

35. Phillips SM, Summerbell C, Hobbs M, et al. A systematic review of the validity, reliability, and feasibility of measurement tools used to assess the physical activity and sedentary behaviour of pre-school aged children. *International Journal of Behavioral Nutrition and Physical Activity*. 2021;18(1):1-28. doi:10.1186/s12966-021-01132-9

36. Sallis JF, Owen N, Fotheringham MJ. Behavioral epidemiology: A systematic framework to classify phases of research on health promotion and disease prevention. *Annals of Behavioral Medicine*. 2000;22(4):294-298. doi:10.1007/BF02895665

37. Kariippanon KE, Chong KH, Janssen X, et al. Levels and Correlates of Objectively Measured Sedentary Behavior in Young Children: SUNRISE Study Results from 19 Countries. *Med Sci Sports Exerc*. 2022;54(7):1123-1130. doi:10.1249/MSS.0000000000002886

38. Katzmarzyk PT, Mason C. The Physical Activity Transition. *J Phys Act Health*. 2009;6(3):269-280. doi:10.1123/jpah.6.3.269

39. Meyer T. Vaccination in athletes, affordable research tools for all and the opportunities arising from publicly available data. *J Sci Med Sport*. 2022;25(12):949. doi:10.1016/j.jsams.2022.11.002

Chapter 2: Literature review

2.1 Introduction

The literature review chapter provides the context of the research work in this thesis in relation to published evidence globally and from LMICs in SSA contexts. The chapter is divided into seven main sections. *Section 2.2* presents an overview of NCDs and related childhood overweight/obesity, which provided the basis for the development of the global movement behaviour guidelines. *Section 2.3* describes childhood obesity and the four global 24-hour movement behaviour guidelines for the early years. This section discusses the basis for developing the guidelines and then moves on to describe the definition and measurement methods for each of the four guidelines, namely physical activity, restrained sitting, screen time, and sleep duration.

Furthermore, *Section 2.4* presents evidence on the prevalence and correlates of meeting all global 24-hour movement behaviours among 3- and 4-year olds globally and in SSA settings. *Section 2.5* describes surveillance of the global movement behaviours in 3–4 year olds globally, with particular focus on the SUNRISE International Study that is underpinning the work presented in this thesis. *Section 2.6* discusses the research gap and provides justification for the work presented in this thesis. *Section 2.7* summaries the information addressed in the literature review chapter.

2.2 Non-communicable diseases and obesity

Non-communicable diseases (NCDs) are a group of chronic diseases that are generally long duration, slow-progressing, and are not transmitted from person to person.[1] The main types of NCDs include cardiovascular diseases, cancers, chronic respiratory diseases, and diabetes.[2] Globally, NCDs are among the leading causes of death,[3] accounting for 74% of all deaths, which is equivalent to about 41 million deaths annually.[2] The burden of NCDs has a disproportionate impact on LMICs where 77% of all NCD-related deaths occur as noted in Chapter 1.[2] In SSA, a region that is already battling communicable diseases like HIV/AIDS and malaria, the burden of NCDs continues to increase. For example, the burden of NCDs, measured as disability adjusted life years (DALYs), increased by 67% from 1990 to 2017 in SSA.[4] In Malawi, NCDs represent a significant health challenge, accounting for an estimated 43% of all deaths in the country in 2019 as earlier noted.[5] Like in most LMICs globally, economic transitions, urbanisation, and lifestyle changes occurring in SSA countries are contributing to the rise in NCDs.[4] A more detailed description of Malawi as a context is given in the preface section of Chapter 5.

Although NCDs typically manifest in adulthood, evidence indicates that risk factors for these diseases, such as physical inactivity, unhealthy diet, and overweight/obesity, can develop throughout childhood.[1,2,6–9] Thus, childhood growth and development have a substantial impact on long-term health and quality of life.[9] While unhealthy diet is a critical risk factor for NCDs and obesity, analysis of dietary patterns/behaviours is beyond the scope of this thesis as earlier mentioned. Nevertheless, it is worth to note that recent evidence suggests complex interactions between movement behaviours and dietary patterns in young and older children.[10–12]

Globally, childhood overweight/obesity is a growing public health crisis,[13] with at least 37 million children under 5 worldwide estimated to have been overweight or obese in 2022.[14] Across Africa, overweight/obesity is prevalent among primary-school children and is considerably more widespread than is recognised.[15] Childhood overweight/obesity has several short- and long-term health consequences, including adulthood obesity and related NCDs and premature mortality later in life.[8,14,16–20] As such, addressing the risk factors for childhood overweight/obesity would offer substantial public health benefits across the lifespan, including tackling the obesity pandemic globally.[8]

Lack of physical activity is a well-established risk factor for overweight/obesity and NCDs,[14,16,20] which is associated with the 'physical activity transition' seen in SSA.[21,22] This physical activity transition occurs when societies shift away from 'traditionally' active lifestyles to a technologically dependent 'westernised' sedentary lifestyle (often characterised by increased reliance on motorised transportation and prolonged use of electronic screen devices) as urbanisation and economic development progresses.[21,23] These lifestyle changes may increase risk factors for NCDs and related obesity,[21,23] thereby further increasing the burden of NCDs in LMICs.[23]

2.3 Childhood obesity and the global 24-hour movement behaviour guidelines for the early years

The early years, typically from 0 to 4 years, are a critical period for child's health, growth, and development.[24,25] This period is critical for fostering healthy habits and behaviours, as these may be tracked in later years, thus potentially shaping future health and related behaviours.[26,27] The WHO Commission on Ending Childhood Obesity (ECHO) report in 2016 highlighted the importance of movement behaviours (physical activity, sedentary behaviours, and sleep) in early years to obesity development and to maintenance of obesity in childhood.[20] That understanding produced the motivation for WHO to publish the first global guidelines on movement behaviours (physical activity, sedentary behaviours, and sleep) for the under 5s in 2019.[25]

These behaviours, collectively referred as '24-hour movement behaviours,' are fundamental components of a child's healthy growth and development and a key component for obesity prevention in young children.[25] As earlier mentioned, scholars have emphasised focusing on these behaviours across a 24-hour period to acknowledge the importance of a 'whole day' and a 'holistic approach' for optimal growth and greater health outcomes in children.[28] This holistic approach is also important given the interconnectedness of the various movement behaviours to childhood overweight/obesity and other health indicators in children.[29] Evidence from a 2017 systematic review[30] suggests that meeting all 24-hour movement guidelines has favourable health outcomes in young children, including adiposity, motor development, and fitness, as summarised in *Table 2-1*. More recent evidence confirms these associations, with a 2020 systematic review and meta-analysis of the association between meeting all 24-hour movement behaviours across the lifespan finding that compliance was favourably associated with adiposity, socio-cognitive development (including language acquisition, executive function, and social skills), health-related quality of life, and bone and skeletal health among 3–4 year olds.[31] A 2021 systematic review also found favourable association between meeting more guidelines and psychosocial health in early years (0–5 years).[32] It is worth noting that the evidence base might well have expanded and guideline updates are likely –current estimate is that these should be underway this year and published by about 2030.[33]

The global WHO 24-hour movement behaviour guidelines were developed based on modern evidence-based processes and aligned with the Australian[34] and Canadian[35] guidelines. The development processes involved formation of research questions, systematic searching, synthesis and appraisal of literature for evidence, and development of the guidelines based on this synthesis.[25] These guidelines were developed to address the lack of global guidance on physical activity for young children and in response to the recommendations of the 2016 ECHO report as earlier noted.[25] The global guidelines apply to all healthy children below the age of five regardless of their gender, cultural, or socioeconomic backgrounds. The guidelines have been developed separately for infants (<1.0 year), children 1.0–2.9 years, and children 3.0–4.9 years, as discussed below.

Table 2-1: Evidence summary of studies reporting associations between combinations of 24-hour movement behaviours and health outcomes among 0–4 year olds based on 2017 evidence.

Health outcome	Number of studies (participants)	Combinations of behaviours (number of studies with favourable associations)	Association	Quality of evidence
Adiposity	• RCTs (2; n=1245) • Non-randomised (1; n=86) • Longitudinal (2; n=1827) • Cross-sectional (3; n=3888)	• Physical activity and sedentary behaviour (3) • Sleep and sedentary behaviour (1)	Favourable in 4 studies	Very low to low
Motor development	• RCTs (2; n=1245)	• Sedentary behaviour and physical activity (2)	Favourable in 2 studies	Low
Fitness	• Cross-sectional (1; n=307)	• Sedentary behaviour and physical activity (1)	Favourable in 1 study	Very low
Growth	• RCTs (2; n=83) • Longitudinal (1; 248)	• Sedentary behaviour and physical activity (0)	No association	Very low to moderate

Adapted from Kuzik et al. (2017),[30] and the authors assessed the quality of evidence using the Grading of Recommendations, Assessment, Development and Evaluations (GRADE) framework.[36] The framework is used to evaluate evidence quality based on study design, risk of bias, inconsistency, indirectness, imprecision, and other factors; RCT = Randomised controlled trial.

2.3.1 Physical activity

Definition and the global physical activity guideline

The WHO defines physical activity as bodily movements that results in energy expenditure beyond the resting state, which may include activities such as jumping, walking, cycling, dancing, etc.[25] For optimal growth and development, the WHO recommends that infants should be physically active several times a day, which includes being in prone position for not less than 30 minutes/day and children aged 1–2 years should spend not less than 180 minutes/day in physical activity. While for 3–4 year olds, the WHO recommends that they should spend not less than 180 minutes/day in TPA, which should include not less than 60 minutes/day of moderate- to vigorous- intensity physical activity (MVPA).[25] MVPA is defined as physical activity with energy cost of at least 3 times the individuals resting metabolic rate.[37]

Physical activity has several health benefits in children and across the life-span,[16,25] and evidence suggests that physical activity in early childhood can be tracked to later years.[26] *Table 2-2* presents summary of the evidence for physical activity associations with various health outcomes among 3–4 year olds that informed the global guidelines.[25,38] Similar evidence base for infants and toddlers is available elsewhere.[38] As earlier noted, the global guidelines were developed through modern evidence-based processes that included assessing the quality of evidence for each associated health outcome using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) framework.[36] It is worth noting that the evidence base is from 2019 and might well have expanded since then, with recent studies from LMICs providing additional support for these associations.[39–42] However, guideline updates are likely and currently estimated to be underway this year and published by 2030.[33]

Table 2-2: Evidence summary of studies reporting physical activity associations with health outcomes among 3–4 year olds based on 2019 evidence.

Health outcome	Study design (number of studies; total number of participants)	Summary of evidence	Association	Quality of evidence
Total physical activity				
Adiposity	• RCTs (3; n=1647) • Longitudinal studies (3; n=486) • Case-control (1; n=1281) • Cross-sectional (17; n=17,254)	• RCTs: No association in 3 studies. • Longitudinal: *Favourable* in 1 study, no association in 2 studies. • Case-control: No association in 1 study. • Cross-sectional: *Favourable* in 5 studies, unfavourable in 3 studies, no association in 9 studies.	Mixed (primarily favourable)	High
Motor development	• RCTs (2; n=1564) • Cross-sectional (4; n=1094)	• RCTs: *Favourable* in 1 study, no association in 1 study. • Cross-sectional: *Favourable* in 3 studies, unfavourable in 1 study.	Favourable	Moderate
Psychosocial health	• RCT (1; n=1467) • Longitudinal (2; n=9989) • Cross-sectional (1; n=216)	• RCT: No association in 1 study. • Longitudinal: *Favourable* in 1 study, no association in 1 study. • Cross-sectional: No association in 1 study.	Mixed	Moderate
Cognitive development	• RCTs (3; n=271)	• RCTs: *Favourable* in 3 studies.	Favourable	High

	• Cross-sectional (1; n=216)	• Cross-sectional: No association in 1 study.		
Fitness				
Cardiorespiratory	• Longitudinal (1; n=123) • Cross-sectional (2; n=594)	• Longitudinal: *Favourable* in 1 study. • Cross-sectional: *Favourable* in 2 studies.	Favourable	Very low
Muscular fitness, speed-agility	• Cross-sectional (1; n=307)	• Cross-sectional: *Favourable* in 1 study.		Very low
Bone and skeletal health	• Cross-sectional (2; n=1751)	• Cross-sectional: *Favourable* in 1 study, no association in 1 study	Favourable	Very low
Cardiometabolic health				
Cholesterol and triglycerides	• Longitudinal (1; n=123)	• Longitudinal: No association in 1 study.	No association	Very low
Clustered risk scores	• Cross-sectional (2; n=994)	• Cross-sectional: *Favourable* for boys only in 1 study.	Favourable (boys only)	Very low
Blood pressure	• Cross-sectional (4; n=684)	• Cross-sectional: Unfavourable in 1 study, no association in 3 studies.	Mixed	Very low
Sleep				
Duration	• Cross-sectional (1; n=216)	• Cross-sectional: More active children slept 55 minutes less at night.	Unfavourable	Low
Night awakening	• Cross-sectional (1; n=216)	• Cross-sectional: More active children were awake 16-19 minutes more at night.	Unfavourable	Low
Risks/Injury	No evidence			

Moderate-to-vigorous physical activity				
Adiposity	• RCTs (3; n=2704)	• RCTs: *Favourable* in 1 study, no association in 2 studies.	Predominantly favourable	Low
	• Longitudinal (2; n=426)	• Longitudinal: *Favourable* in 2 studies.		
	• Cross-sectional (15; n=3200	• Cross-sectional: *Favourable* in 6 studies, unfavourable in 3 studies, no association in 7 studies.		
Motor development	• RCTs (2; n=1550)	• RCTs: *Favourable* in 1 study, no association in 1 study.	Favourable	Moderate
	• Longitudinal (1; n=116)	• Longitudinal: *Favourable* for locomotor skills in 1 study.		
	• Cross-sectional (3; n=923)	• Cross-sectional: *Favourable* in 3 studies.		
Psychosocial health	• RCT (1; n=1467)	• RCT: No association in 1 study.	Mixed	Moderate
	• Cross-sectional (2; n=5152)	• Cross-sectional: Unfavourable in 1 study, no association in 1 study.		
Cognitive development	• RCTs (3; n=271)	• RCTs: *Favourable* in 2 studies, mixed results in 1 study.	Favourable	High
	• Non-randomised (1; n=54)	• Non-randomized: *Favourable* in 1 study.		
	• Cross-over (1; n=139)	• Cross-over: *Favourable* in 1 study.		
	• Cross-sectional (1; n=216)	• Cross-sectional: No association in 1 study.		
Fitness				

Cardiorespiratory	• Longitudinal (1; n=138) • Cross-sectional (1; n=307)	• Longitudinal: *Favourable* in 1 study. • Cross-sectional: *Favourable* in 1 study.	Favourable	Very low
Muscular fitness, speed-agility	• Longitudinal (1; n=138) • Cross-sectional (1; n=307)	• Longitudinal: *Favourable* for lower-body and speed/agility in 1 study. • Cross-sectional: *Favourable* for standing long jump and speed-agility in 1 study.	Favourable	Very low
Bone and skeletal health	• Cross-sectional (3; n=2173)	• Cross-sectional: *Favourable* in 2 studies, no association in 1 study.	Favourable	Low
Cardiometabolic health				
Cholesterol and triglycerides	• Cross-sectional (1; n=994)	• Cross-sectional: No association in 1 study.	No association	Very low
Clustered risk scores	• Cross-sectional (1; n=994)	• Cross-sectional: No association in 1 study.	No association	Very low
Sleep duration	• Cross-sectional (2; n=243)	• Cross-sectional: No association in 2 studies.	No association	Low
Risks/Injury	No evidence			

Adapted from Reilly et al. (2020),[38] with stylistic modifications, including reformatted presentation, and inclusion of information relevant to this thesis. All original evidence assessments and associations preserved. The authors[38] assessed the quality of evidence using the Grading of Recommendations, Assessment, Development and Evaluations (GRADE) framework.[36] The framework is used to evaluate evidence quality based on study design, risk of bias, inconsistency, indirectness, imprecision, and other factors. RCT = Randomised controlled trial; MVPA = Moderate-to-vigorous intensity physical activity.

Measurement methods

Several methods have been developed and are currently being used for measuring physical activity in young children for determining the levels and assessing compliance with the global physical activity guidelines, monitoring trends, informing and evaluating physical activity interventions, and informing health policies. The most commonly used methods include subjective measures such as proxy reports from parents/caregivers or teachers and objective measures using devices such as accelerometers and pedometers.[43]

Proxy reports are mostly used in large-scale population studies because young children are unable to correctly report on their physical activity, and proxy reports are less expensive and easier to administer than objective methods.[43] However, proxy reports, e.g., from parents, may have limited validity because they are subject to recall and social desirability bias,[44] and parents may not be aware of all of their child's physical activity, especially when the child is away from home for periods of time, e.g., when at the preschool or being cared for by others. Most proxy questionnaires used for reporting child's physical activity were developed based on evidence from high-income countries (HICs), which may have limited validity in other contexts, such as LMICs, due to differences in sociocultural and economic backgrounds as shown by a 2018 and 2021 systematic review.[45,46] Such evidence demonstrates concerns over the limited validity of subjective measures for assessing physical activity in young children even in HICs, which creates greater concern for their practical utility in other cultural context.[47]

Objective measurement methods using accelerometers and pedometers are often used to overcome biases from proxy reports. Accelerometers are small lightweight devices that children can wear as a wristwatch or around the waist using an adjustable belt, and they provide valid and reliable physical activity measures in young children.[48,49] Several research grade accelerometers are available, but the most commonly used include ActiGraph and *activ*PAL™ accelerometers.[50] Accelerometers, such as ActiGraph accelerometers, record the body's accelerations during movements and transform the raw acceleration data to activity counts and then classified into intensities (i.e., sedentary, light, moderate, vigorous) while *activ*PAL™ uses posture classification (i.e., sitting/lying, moving/stepping and standing) over a predetermined time period or epoch.[44,50,51] A 2021 systematic review concluded that objective measurement using accelerometry, such as ActiGraph and *activ*PAL™ accelerometers, provide valid measures and are feasible for measurement of physical activity in 3–7 year old children, though some methodological limitations remain, including the complexity of data analysis and subjective decision-making over aspects of the method such as epoch length and cut points.[46]

Accelerometers can also record activities in the form of step counts depending on how they have been initialised (e.g., when using ActiGraph accelerometers). Step counting offers practical utility for assessing physical activity in larger population and surveillance studies because steps are relatively easier to measure and readily understandable by both children and adults compared to accelerometer-based activity counts.[52] However, accelerometry-based methods are less often used in large population studies due to their associated costs and complexity of the measurements.[44,53,54] For these reasons, step counting, using cheaper devices like pedometers, has gained significant interest as a simple low-cost alternative to accelerometer-based activity counts for assessing physical activity in both children and adults.[55–61] Thus, step-based measures offer a greater opportunity for use in global surveillance studies, particularly in resource-limited settings such as LMICs.

Several validation studies of pedometer step counting against accelerometry for assessing physical activity in young children showed moderate to high correlation (r) ranging between 0.59 to 0.95,[49,54,62–66] as shown in *Table 2-3*. While this evidence supports the utility of step based measures for assessing physical activity among young children in large-scale studies and monitoring compliance with the global guidelines in this age group, the studies were predominantly conducted in HICs.[49,54,62–66] This may limit the generalisability of the evidence in other context due to cultural and socioeconomic variations among populations in LMICs compared to HICs.

Furthermore, the current global physical activity guideline for young children is based on activity intensity and duration.[25] For example, 3–4 year olds are recommended to spend a minimum of 180 minutes per day in TPA as earlier mentioned. However, given the public health implications of step-based measurements (e.g., easy to measure and are readily understandable by the public),[52] researchers have proposed varying step count thresholds ranging 6000–11,500 steps/day, based on accelerometry activity duration and intensity counts, as equivalent to 180 minutes of TPA per day for children aged 3–4 years.[55–57] Thus, there is currently no consensus among scholars on the step count threshold that corresponds to the 180 minutes per day of TPA in 3–4 year olds.

Table 2-3: Evidence summary of studies reporting validity of step counting for assessing physical activity in 3–4 year old children

Study (Year)	Study design and setting	Participants (sample size)	Device	Criterion measure and procedure	Validity	Reliability
McKee et al. (2005)[64]	Cross-sectional Nursery school setting, Northern Ireland	3–4 year olds (n=30)	Yamax Digiwalker DW-200 pedometer	Direct observation (CARS). Children were monitored for one hour while wearing the pedometer.	Moderate to high correlation (r=0.64–0.95).	Not reported
Cardon & De Bourdeaudhuij (2007)[65]	Cross-sectional Preschool settings, Belgium	4–4.5 year olds (n=76)	Yamax Digiwalker SW-200 pedometer.	ActiGraph MTI 7164 accelerometer Children wore the devices concurrent for 4 consecutive days.	Strong correlation (r=0.73, p<0.001).	Not reported
Oliver et al. (2007)[54]	Cross-sectional Childcare centre setting, New Zealand	3.0–4.8 year olds (n=13)	Yamax Digiwalker SW-200 pedometer	Direct observation (CARS) Children were observed during 35-minutes of unstructured indoor and outdoor free-play. Reliability was assessed during straight line walking with pedometers worn on three	Moderate correlation (r=0.59, p=0.04)	Non-significant variability observed in pedometer accuracy.

				sites (left hip, right hip and back).		
Tanaka & Tanaka (2009)[66]	Cross-sectional Kindergarten or nursery school setting, Japan	4–6 year olds (n=157)	Lifecorder EX accelerometer	ActivTracer accelerometer Children wore the two monitors for 6 consecutive days	Strong correlation (r=0.83, p=0.001)	Not reported
Pagels et al. (2010)[62]	Cross-sectional Preschool settings, Sweden and USA	3–5 year olds (n=55)	Yamax SW200 pedometer and	ActiGraph GT1M accelerometer Children wore the devices during preschool time over 5 consecutive days.	Moderately high correlation mean step counts (r=0.67, p<0.001).	Not reported
De Craemer et al. (2015)[49]	Cross-sectional Preschool settings, Belgium	4–6 year olds (n=41)	Omron Walking Style Pro pedometer	ActiGraph GT1M accelerometer Children wore the devices for 5 consecutive days.	Moderately high correlation (r=0.64–0.65).	High inter-monitor reliability (ICC=0.94–0.96)
Sharp et al. (2017)[63]	Cross-sectional Nursery settings, UK	3–4 year olds (n=56)	Fitbit Zip	Direct observation (Video)	Fitbit 1: r=0.77; mean bias 22.8±19.1 steps	High (ICC=0.77)

		Children wore two Fitbit Zip accelerometers during timed walking tasks.	Fitbit 2: r=0.77; mean bias 25.2±23.2 steps

CARS = Children's Activity Rating Scale; MVPA = Moderate-to-vigorous intensity physical activity; ICC = Interclass coefficients.

2.3.2 Sedentary behaviour

Definition and the global sedentary behaviour guideline

Sedentary behaviour is defined as any awake behaviour with an energy expenditure of less than 1.5 metabolic equivalents (METs) when sitting, reclining, or lying down.[67,68] Generally, young children spend time in sedentary behaviour while using screen-based devices (e.g., watching television or playing computer games), which is referred to as sedentary screen time,[68] or restrained in a stroller, pram, car seat, high chair, or wrapped on the back of parent/caregiver. For optimal healthy growth and development, the WHO recommends that children below the age of five should not be restrained for more than one hour at a time.[25] In addition, while screen time was not recommended for children below two years, the WHO recommends that 2–4 year olds should limit their daily sedentary screen time to less than an hour.[25]

Evidence suggests that sedentary behaviour, particularly screen time, is associated with various health outcomes in young children,[38] and may influence sedentary lifestyles in later years.[69] *Table 2-4* presents a comprehensive summary of evidence on the association between restrained sitting and sedentary screen time and various health outcomes among 3–4 year olds through the GRADE assessment[36] that informed the development of the global guideline.[25,38] As earlier noted, the evidence base is from 2019 and might well have expanded considerably since then, with recent studies from LMICs providing additional support for these associations.[39–42] However, guideline updates are likely and currently estimated to be underway this year and published by 2030.[33]

Measurement methods

Similar to physical activity, sedentary behaviour in young children can be measured objectively using activity monitors (e.g., accelerometers) and direct observation or subjectively using proxy reports and diaries from parents/caregivers or teachers.[43,46] While the objective and subjective methods can be used independently in research, researchers have concurrently used both methods to overcome the limitations from using a single method.[70] For example, researchers combine accelerometry to measure total sedentary time with proxy questionnaires to assess screen time in order to get a more comprehensive assessment of child's sedentary behaviours. However, resource constraints and capacity gaps may limit the use of combined methods in resource-limited settings, so the use of a cheaper method may be preferred in such contexts.

Direct observations are expensive, time consuming, require expertise in data processing and analysis,[46,54] and are therefore not practically suitable for large-scale studies as earlier noted. Accelerometers provide valid measurements and are used in large-scale studies; however, these devices are expensive, require expertise in data processing and analysis, and do not provide the type and context of the behaviour.[46,71] In addition, accelerometers have limited ability to distinguish between sitting and standing still when worn on the hip, though thigh-worn devices like *activ*PAL™ can accurately detect posture changes,[72] and they may lack comparability across studies and brands due to the differing data processing protocols.[70]

Proxy reports based on questionnaires or diaries are commonly used in large-scale studies because they are less expensive, relatively simple to administer, and can be used to provide the type and context of the behaviour.[46,70] However, proxy reports are subject to recall or social desirability bias as noted above.[70] Nevertheless, proxy questionnaires remain important for use in surveillance studies to capture the contextual information about specific sedentary behaviours (e.g., sedentary screen time) in order to better understand the impact of electronic screen devices on the health and development of children.[46,73]

Table 2-4: Evidence summary of studies reporting associations of sedentary behaviour with health outcomes among 3–4 year olds based on 2019 evidence.

Health outcome	Study design (number of studies; total number of participants)	Summary of evidence	Association	Quality of evidence
Restrained sitting time (e.g., car seat, sling, highchair)				
Adiposity	Longitudinal (2; n=5493)	Longitudinal: No association between time in car and adiposity in 2 studies.	No association	Very low
Motor development	No evidence			
Psychosocial health	No evidence			
Cognitive development	No evidence			
Bone and skeletal health	No evidence			
Cardiometabolic health	No evidence			
Fitness	No evidence			
Screen time (TV, phone, playing computer games, using the internet				
Adiposity	• RCTs (1; n=412) • Longitudinal (8; n=33,376) • Case control (4; n=1638) • Cross-sectional (48; n=96,342)	• RCT: No difference in BMI between intervention and control in 1 study. • Longitudinal: Unfavourable in 5 studies, no association in 3 studies. • Case-control: Unfavourable in 3 studies, no association in 1 study.	Unfavourable	Low

		• Cross-sectional: Unfavourable in 12 studies, no association in 16 studies, *favourable* in 3 studies.		
Motor development	No evidence			
Psychosocial health	• RCTs (1; n=412)	• RCT: Intervention reduced aggressive and delinquent behaviours at 9 months in 1 study.	Unfavourable	Low
	• Longitudinal (4; n=8401)	• Longitudinal: *Unfavourable* in 2 studies, no association in 3 studies.		
	• Cross-sectional (7; n=12582)	• Cross-sectional: *Unfavourable* in 5 studies, no association in 2 studies, favourable in 1 study.		
Cognitive development	• Longitudinal (5; n=4375)	• Longitudinal: *Unfavourable* in 2 studies, no association in 3 studies.	Unfavourable	Very low
	• Cross-sectional (5; n=3435)	• Cross-sectional: *Unfavourable* in 3 studies, no association in 2 studies.		
Bone and skeletal health	• Cross-sectional (1; n=1512)	• No association in 1 study.	No association	Very low
Cardiometabolic health	• Cross-sectional (1; n=276)	• No association between TV time >2hr/day and cardiometabolic health in 1 study.	No association	Very low
Fitness	No evidence			
Objectively measured sedentary behaviour				
Adiposity	• Longitudinal (2; n=249) • Cross-sectional (8; n=2154)	• Longitudinal: No association in 2 studies.	No association	Very low

		• Cross-sectional: Unfavourable in 1 study, no association in 8 studies.		
Motor development	Cross-sectional (1; n=198)	No association in 1 study.	No association	Low
Psychosocial health	Cross-sectional (1; n=216)	No association in 1 study.	No association	Low
Cognitive development	Cross-sectional (1; n=216)	No association in 1 study.	No association	Low
Bone and skeletal health	Cross-sectional (1; n=1512)	No association in 1 study.	No association	Very low
Cardiometabolic health	No evidence			
Fitness	Longitudinal (1; n=138)	No association in 1 study.	No association	Very low

Adapted from Reilly et al. (2020),[38] with stylistic modifications, including reformatted presentation, and inclusion of information relevant to this thesis. All original evidence assessments and associations preserved. The authors[38] assessed the quality of evidence using the Grading of Recommendations, Assessment, Development and Evaluations (GRADE) framework.[36] The framework is used to evaluate evidence quality based on study design, risk of bias, inconsistency, indirectness, imprecision, and other factors. It is worth noting that the evidence base is from 2019 and might well have expanded considerably since then, with recent studies from LMICs providing additional support for these associations.[39–42] RCT = Randomised controlled trial; BMI = Body mass index; TV = Television

2.3.3 Sleep health and behaviour

Definition and the global sleep duration guideline

Healthy sleep in young children encompasses various dimensions of sleep characterised by child- or parent/caregiver-reported satisfaction, age-appropriate duration, optimal sleep timing, high efficiency, sustained alertness throughout awake time, and healthy sleep habits.[74] The WHO defines sleep behaviour as the "duration and timing of sleep", which includes both daytime naps and nighttime sleep for the under 5s.[25] Sleep is essential in young children because it has an impact on their growth, emotional and cognitive development, and overall health and wellbeing.[75] The WHO global guidelines recommend good quality sleep, including naps, for infants (<1 year) of up to 17 hours per day, children 1–2 years old of 11 to 14 hours per day, and 3–4 year olds of 10 to 13 hours per day. *Table 2-5* provides a summary of evidence of the associations of sleep duration with various health outcomes that informed the development of the global guideline.[25,38] The quality of the evidence was assessed using the GRADE framework[38] as earlier noted. It is worth noting that the evidence base is from 2019 and might well have expanded considerably since then as earlier noted, with recent studies from LMICs providing additional support for these associations.[39–42] However, guideline updates are likely and currently estimated to be underway this year and published by 2030.[33]

Measurement of sleep duration

Measurement of sleep in young children is challenging because the choice of the method depends on the sleep dimension of interest, age, and complexity of measurement instrument.[76] Most research has mainly focused on assessing sleep duration[77,78] and based on studies conducted in middle- and high-income countries.[77] This could be partly because it may be relatively easier to measure and understand sleep duration than the other dimensions of sleep (e.g., timing, quality, consistency), hence it could potentially be translated into policy and practice. Besides, the global sleep guideline explicitly provides age-specific recommendations for sleep duration,[25] which makes it easier to set targets and measure them.

The most commonly used measurements in young children include objective methods using accelerometry and subjective methods using proxy reported questionnaires or diaries.[75,77,78] While research-grade accelerometers such as ActiGraph provide valid measurements of sleep duration and are increasingly being used to measure sleep in young children, they have limited use in large-scale studies, particularly in resource-limited settings like LMICs. This is due to their associated higher costs and the complexity of the measurement method.[76] Consequently, questionnaires are widely used in large-scale studies for measurement of sleep in young children because they are relatively cheap and easier to administer.[76]

Despite the lack of standardised measurement methods[76] and proven reliability and validity[79] for most proxy reported sleep measures in young children, recent evidence suggests that the SUNRISE parent questionnaire provides an accurate measure of sleep timing and duration against accelerometry in young children globally.[80] This provides an important step for improving surveillance of sleep behaviour in young children globally, particularly in LMICs where expertise and resource constraints may limit the use of objective methods.[47,71,81–84]

Table 2-5: Evidence summary of studies reporting associations of sleep duration with health outcomes among 3–4 year olds based on 2019 evidence.

Health outcome	Study design (number of studies; total number of participants)	Summary of evidence	Association	Quality of evidence
Adiposity	• Longitudinal studies (10; n=29,276) • Case-control (2; n=546) • Cross-sectional (6; n=27,055)	• Longitudinal: No association in 4 studies, favourable in 5 studies, inverse in 1 study. • Case-control: No association in 2 studies. • Cross-sectional: Favourable in 4 studies, association in boys only in 1 study, inverse association in 1 study.	Favourable	Very low
Emotional regulation	• Cross-sectional (5; n=2389)	• Cross-sectional: No association in 2 studies, favourable in 2 studies, mixed in 1 study.	Favourable	Very low
Cognitive development	• Longitudinal (1; n=67) • Cross-sectional (3; n=7459)	• Longitudinal: Favourable in 1 study. • Cross-sectional: Unfavourable in 2 studies, mixed in 1 study.	Favourable	Very low
Motor development	No evidence			
Growth	No evidence			
Physical activity	• Longitudinal (1; n=2984) • Cross-sectional (2; n=2032)	• Longitudinal: No association in 1 study. • Cross-sectional: No association in 1, association only in boys in 1 study.	No clear association (favourable only in boys)	Very low

Sedentary behaviour	• Longitudinal (1; n=2984) • Cross-sectional (2; n=40,841)	• Longitudinal: Shorter sleep associated with increased screen time in 1 study. • Cross-sectional: Shorter sleep associated with increased screen time in 2 studies.	Unfavourable	Very low
Quality life/ wellbeing	• Longitudinal (2; n=13,237)	• Longitudinal: Short sleep associated with poor quality of life in 1 study, no association in 1 study.	Mixed	Very low
Risks/Injuries	• Cross-sectional (3; n=538)	• Cross-sectional: Shorter sleep associated with increased injury risk in 2 studies, no association in 1 study.	Unfavourable	Very low

Adapted from Reilly et al. (2020),[38] with stylistic modifications, including reformatted presentation, and inclusion of information relevant to this thesis. All original evidence assessments and associations preserved. The authors[38] assessed the quality of evidence using the Grading of Recommendations, Assessment, Development and Evaluations (GRADE) framework.[36] The framework is used to evaluate evidence quality based on study design, risk of bias, inconsistency, indirectness, imprecision, and other factors. It is worth noting that the evidence base is from 2019 and might well have expanded considerably since then, with recent studies from LMICs providing additional support for these associations.[39–42] RCT = Randomised controlled trial.

2.4 Prevalence and correlates of meeting the global 24-hour movement behaviour guidelines among 3–4 year olds

2.4.1 Prevalence of meeting 24-hour movement behaviour guidelines

The publication of the global guidelines on 24-hour movement behaviours for the under 5s in 2019 has received considerable scholarly attention globally. Notably, studies have been conducted to provide benchmarks for surveillance studies, determine and monitor the levels of compliance with the global guidelines, and assess correlates of compliance with the guidelines. As earlier noted, much evidence reviewed systematically on compliance with the global guidelines is mostly for physical activity[29,47] and comes mainly or entirely from studies conducted in HICs.[31] The lack of evidence is overwhelmingly limited in LMICs across SSA, as shown in *Table 2-6*.

For example, only one South African study was included in a 2021 systematic review and meta-analysis that included 18 studies from 11 countries. In this study, Feng et al.[32] found that 13% of children aged 0 to <5 globally met all three 24-hour movement guidelines (physical activity, screen time, and sleep duration). They also found that the proportions of meeting individual guidelines were 67%, 28%, and 21% for physical activity, screen time, and sleep duration, respectively.[32] A 2022 systematic review and meta-analysis, Tapia-Serrano et al.[85] also only found one study from SSA (specifically South Africa) out of 63 studies from 23 countries. Tapia-Serrano et al.[85] reported that only 11% of preschoolers aged 3–5 years met all three 24-hour movement guidelines (physical activity, screen time, and sleep duration), and that meeting the guidelines was higher in the African region (17%) compared to other regions, ranging from 3% in south America to 11% in Oceanian, as well as among boys (7%) than girls (4%). It is worth noting that both systematic reviews[32,85] assessed meeting three global 24-hour movement guidelines by specifically examining physical activity, screen time, and sleep, but did not include the fourth guideline on restrained sitting time based on the WHO recommendation.[25] Besides, authors for the two systematic reviews[32,85] did not specify if meeting the physical activity guideline included TPA, MVPA, or both.

The lack of evidence from SSA is supported by a 2020 systematic review that found only two pilot studies from South Africa based on the same sample of 3–4 year olds.[86] In addition, while only South African studies were reported in the 2021 and 2022 systematic reviews and meta-analyses noted above,[32,85] the country is classified as an upper-middle income country,[87] which may limit generalisability of the findings to low-income settings within the region. Besides, the sample for the South African study reported by Feng et al.[32] included infants and toddlers below 3 years, rather than focusing specifically on 3–4 year olds. Additionally, the geographical and sex differences reported by Tapia-Serrano et al.[85] were based on the overall sample that included children and adolescents aged 6–18 years.

Until recently, only two studies have reported the levels of compliance with the global 24-hour movement behaviour guidelines from a low-income SSA context. Chong et al.[88] found that 14% of 3–4 year olds from 33 diverse countries globally met all three 24-hour movement guidelines including physical activity, screen time, and sleep duration. While the pooled analysis study[88] included Malawian 3–4 year olds that participated in a SUNRISE pilot study (n=54), children from low-income countries were largely under-represented in the study.[88] Additionally, the Chong et al.[88] global study did not include compliance with the restrained sitting guideline to comprehensively and holistically assess all movement behaviours among young children across a 24-hour period as earlier noted.[25,28]

The only large-scale study that has reported compliance with the global guidelines among 3–4 year olds is from Ethiopia,[89] a low-income SSA country. Abdeta et al.[89] found that 58% of children met all three global guidelines, including physical activity, screen time, and sleep, with exceptionally higher proportions meeting the physical activity (96%) and sleep duration (92%) guidelines and 64% met the screen time guideline. While the Ethiopian study findings hold promise,[89] as earlier noted, the use of accelerometry-measured activity counts for assessing physical activity could potentially limit their use to inform evidence policy interventions and surveillance systems in (other) low-income contexts where research capacity and resources are disproportionately limited.[47,71,82–84] In addition, similar to the Chong et al.[88] global study, Abdeta et al.[89] did not include compliance with the restrained sitting guideline to comprehensively and holistically assess all movement behaviours among young children across a 24-hour period, which may overestimate the overall compliance level.

Table 2-6: Evidence summary of studies on the prevalence of meeting the global 24-hour movement behaviour guidelines in young children from low- and middle-income SSA settings

Study (Year)	Design and country	Design and assessments methods	Population and sample	PA (%)	RS	ST (%)	Sleep (%)	All (%)
Feng et al. (2021)[32]	Systematic review and meta-analysis 11 countries (SSA n=1)[a] 18 studies (n=13 studies among 3–4 year olds)	PA: Accelerometry (n=15); Parent reported (n=3) ST: Parent reports (n=18) Sleep: Accelerometry (n=3); parent reported (n=12); accelerometry and activity logs (n=3)	0.0–4.99 years n=8943	67.0	NR	28.3	77.3%	12.8[b]
Tapia-Serrano et al. (2022)[85]	Systematic review and meta-analysis 23 countries (SSA n=1)[a] 63 studies (n=27 among 3–5 year olds)	PA: Accelerometers (n=22); Parent reported (n=4); accelerometry and parent reports (n=1) ST: Parent reported (n=27) Sleep: Accelerometry (n=11); Parent reported (n=16)	3–18 years n=387,435 (3% 3–5 year olds)[c]	NR	NR	NR	NR	11.3[d]

Chong et al. (2024)[88]	33 countries (SSA n=4, including Malawi, Nigeria, South Africa, and Tanzania)	PA (TPA and MVPA): Accelerometers ST: Parent reported Sleep: Parent reported	3–4 years n=7017 (SSA n=286)	49.2	NR	41.8	81.0	14.3[e]
Abdeta et al. (2024)[89]	Ethiopia	PA (TPA and MVPA): Accelerometers ST: Parent reported Sleep: Parent reported	3–4 years	96.1	NR	63.5	91.9	58.0
Munambah et al. (2021)[40]	Zimbabwe	PA (TPA): Accelerometers RS: Parent reported ST: Parent reported Sleep: Parent reported	3–4 years n=81	89.0[f]	51.0	68.0	84.0	23.0
Draper et al. (2020)[39]	South Africa	PA (TPA and MVPA): Accelerometers RS: Parent reported ST: Parent reported Sleep: Parent reported	3–4 years n=88	84.0	89.0	48.0	66.0	26.0

a Only one study from South Africa (Draper et al.[39]) which is classified as upper-middle income country; b 13.5% among preschoolers aged 3–4 year; c preschoolers were defined as 3–5 year olds, but the supplementary file for the Tapia-Serano et al.[85] study included studies that involved infants and toddlers <3.0

years (n=5), older children aged ≥5.0 years (n=16), and one study involved both younger and older children (n=1); d prevalence for meeting the individual behaviours (physical activity, screen time, and sleep duration) not provided; e 16.6% among children from LMIC settings globally (13 countries; n=900); f prevalence of meeting the total physical activity guideline; NR = Not reported; PA = Physical activity; MVPA = Moderate-to-vigorous intensity physical activity; RS = Restrained sitting; ST = Screen time; SSA = Sub-Saharan Africa; TPA = Total physical activity

2.4.2 Correlates of meeting 24-hour movement behaviour guidelines

Based on the Behavioural Epidemiology Framework,[90] understanding factors that influence (or are correlates of) compliance with the 24-hour movement behaviours in young children is essential to develop effective, evidence-based tailored interventions as earlier noted. Research has examined a wide range of correlates drawn across the multiple levels of the Social Ecological Model,[91] including individual-, environmental-, and societal-level factors. However, most correlates studies in young children focused on compliance with individual behaviour guidelines,[92,93] mostly physical activity, with limited evidence on compliance with all global 24-hour movement behaviour guidelines. Additionally, at the start of the work in this thesis as earlier noted, the available evidence was based on studies from HICs, with very limited studies from LMICs, particularly SSA context,[86] as summarised in *Table 2-7*.

As can be seen from *Table 2-7*, only two systematic reviews comprehensively examined correlates of meeting all global 24-hour movement behaviour guidelines.[31,85] A 2022 systematic review and meta- analysis[85] that included over 387,000 participants aged 3–18 years found a sex difference in meeting the global guidelines, with girls significantly less likely to meet all three guidelines (physical activity, screen time, and sleep) than boys. In addition, Tapia-Serrano et al.[85] found that child's age influenced compliance with the global guidelines, with older children less likely to meet the guidelines. Tapia-Serrano et al.[85] also found that country income influenced compliance with all global guidelines combined, with higher compliance in countries with higher Human Development Index (HDI), a composite measure that combines indicators of life expectancy, education, and per capita income to rank countries on their human development.[94]

Furthermore, a 2020 systematic review[31] found that meeting all three 24-hour movement guidelines (i.e., physical activity, screen time, and sleep) was influenced by ethnicity and poverty among 3–4 year olds. It is worth noting that children aged 3–4 years and studies from the SSA context were highly under-represented in both reviews.[31,85] Specifically, SSA studies included in the 2020 review[31] were among older children while the 2022 review[85] included only one South African study that involved 3–4 year olds. Additionally, individual studies for preschoolers (defined as 3–5 year olds) included in the 2022 systematic review and meta-analysis[85] also included infants (<1 year), toddlers (1–2 years), and older children (≥5 years), which does not align with the global recommendations of infants, toddlers and 3–4 year olds.[25]

The limited studies from the SSA context show mixed evidence on the influence of residential setting on compliance with the global guidelines. Two previous studies in South Africa and Zimbabwe found potential differences in compliance with the global guidelines, predominantly by residential setting (i.e., urban vs rural).[39,40] However, the South African[39] and Zimbabwean[40] data were based on pilot studies and did not specifically examine correlates of meeting the global guidelines. In addition, the two countries are classified as MICs[87] and may not reflect the movement behaviours of young children in LIC contexts, as the levels may vary across income groups.[88] However, a later study published in 2024 did not find any significant differences in meeting guidelines between urban and rural children aged 3–4 years across 10 LMICs,[95] all of which are classified as MICs by the World Bank.[87] The only known large study from a low-income SSA setting involved 430 Ethiopian 3–4 year olds published in late 2024 and found that meeting the guidelines was associated with urbanicity but not the child's sex and parental education.[89] Specifically, Abdeta et al.[89] found that rural children were significantly more likely to meet all three guidelines (physical activity [TPA and MVPA], screen time, and sleep duration) compared to their urban counterparts (adjusted OR: 7.41; 95% CI: 4.04, 14.00; $p<0.001$).

Nevertheless, the Ethiopian study[89] emphasises the importance of context-specific research to inform tailored policy interventions in line with the Behavioural Epidemiology Framework.[90] While this evidence holds promise, Abdeta et al.[89] assessed physical activity using accelerometry-measured activity counts which may have limited use in large-scale surveillance studies in resource-limited settings as earlier noted. As such, further research using valid, culturally appropriate methods is urgently needed to identify the most important factors influencing compliance with the global movement behaviour guidelines in young children from low-income SSA settings. This evidence will be essential to inform sustainable national surveillance systems and the development of effective, targeted interventions to promote healthy movement behaviours in young children in these settings.

Table 2-7: Evidence summary of studies reporting correlates of meeting the global 24-hour movement behavior guidelines among young children from low- and middle-income SSA settings.

Study (Year)	Design and setting	Population	Behaviours assessed	Evidence synthesis and key findings
Rollo et al. (2020)[31]	Systematic review n=51 studies (11 among 3–4 year olds)	infants (< 1 year), toddlers (1–2 years), preschoolers (3–4 years), children (5–11 years), youth (12–17 years), adults (18–64 years), and older adults (≥65 years).	24-hour, including PA, sedentary behaviour (or screen time), and sleep.	• Included nine studies involving 3–4 year olds, all from HICs. • All five studies that involved SSA countries (Mozambique n=1; and Kenya and South Africa n=4) were among older children aged 9–11 years. • Did not include meeting the restrained sitting guideline. • Only one study among 3–4 year olds examined correlates and found that compliance with the guidelines was influenced by ethnicity and poverty (SES).
Tapia-Serrano et al. (2022)[85]	Systematic review and meta analysis n=63 studies (n=27 preschoolers) across 23 countries	3–18 years n=387,435	24-hour movement behaviours (PA, ST, and sleep)	• Only one SSA study from South Africa included. • Preschoolers were defined as 3–5 year olds and comprised 3% of the total sample. However, the supplementary file showed that this age group included 22 studies that involved infants and toddlers <3.0 years (n=5), older children aged ≥5.0

				years (n=16), and both younger and older children (n=1). • Did not include meeting the restrained sitting guideline. • Compliance with all three guidelines was higher among preschoolers (11.3%) than children (10.3%), and adolescents (2.7%), but the difference was significant only between preschoolers and adolescents (p<0.001). • There was sex difference in compliance with all three guidelines for the overall sample (p<0.001), with higher prevalence among boys (6.9%) than girls (3.8%), but not among preschoolers (boys 8.6%; girls 6.9%; p=0.470). • Compliance with the guideline was also influenced by country HDI (p<0.001).
Kariippanon et al. (2022)[93]	19 countries	3–5 year n=1071	Sedentary behaviour (objectively measured)	• Evidence from SUNRISE pilot studies from 19 countries, including two middle-income SSA countries (South Africa and Zimbabwe). • Examined levels and patterns of the behaviours, but not compliance with the behaviours.

				• Did not find any significance sex difference in time spend in the behaviour, but there was significant difference by country income group.
Arts et al. (2023)[92]	Systematic umbrella review and expert panel consultation n=21 systematic reviews	0–5.9 years	Physical activity	• Preschoolers were defined as 3.0 to 5.9 years. • Four reviews included studies from Africa. • Child's sex was consistently associated with meeting PA guidelines across studies. • Child's age, parental education, adiposity/BMI, and motor skills were identified as 'most important' determinants/correlates of physical activity in young children.
Abdeta et al. (2024)[89]	Ethiopia	3–4 year olds n=430	24-hour movement behaviours (PA [TPA and MVPA], ST, and sleep)	• Compliance with all three guidelines was significantly influenced by residential setting, with rural more likely to meet the guidelines than urban children (AOR: 7.41; 95%CI: 4.04, 14.00; p<0.001). • Child's sex and parental education were not significantly associated with meeting all three guidelines.

AOR = Adjusted odds ratio; CI = Confidence interval; HIC = High-income country; HDI = Human Development Index; MVPA = Moderate-to-vigorous intensity physical activity; PA = Physical activity; ST = Screen time; SSA = Sub-Saharan Africa; TPA = Total physical activity

2.5 Public health surveillance of global 24-hour movement behaviours in 3–4 year olds

The WHO defines public health surveillance as a systematic and ongoing collection, analysis, interpretation, and timely dissemination of health-related data essential for planning, implementation, and evaluation of public health practice.[96] Effective surveillance systems can provide information useful for serving as an early detection and warning sign for a particular public health problem, monitoring trends and progress toward set goals, evaluating the effectiveness of programmes and interventions, and advocating for public health policies and strategies.[97] Acknowledging the importance of children's healthy movement behaviours and their implication on future health, including tackling NCDs and obesity globally,[25] as well as the achievement of the 2030 Sustainable Development (SDGs),[98] the WHO recommends establishing surveillance systems on physical activity and sedentary behaviour across all age groups, including in young children.[98]

There are currently several global surveillance initiatives for physical activity, sedentary behaviours, and sleep in children and adolescents aged 5 to 18 years and adults. These include: the Global School-based Student Health Survey that involves adolescents aged 13 to 17 years and conducted mostly in LMICs[99]; the Health Behaviour in School-aged Children (HBSC) study that involves adolescents aged 11 to 15 years and conducted in countries in Europe and North America[100]; the Active Healthy Kids Global Alliance Global Matrix (AHKGA-GM) programme which involves 5–17 year olds globally[101]; the International Children's Accelerometry Database (ICAD), which was established in 2010 and involves 3–18 year old children from middle- and high-income countries across Australia, Brazil, Europe, and the US[102]; and the STEPwise approach to NCD risk factor surveillance (STEPS) in adults globally.[103] To date, the SUNRISE International Study of 24-hour movement behaviours in the early years[104] is the only international surveillance initiative that involves children aged 3 to 4 years globally, including from low-income SSA countries. A detailed description of the SUNRISE International Study, which provided the basis for the body of work presented in this thesis, is discussed in the following section.

2.5.1 The SUNRISE International Study of movement behaviours in the early years

As noted above, the body of work in this thesis was partly informed by the SUNRISE International Study,[104] which is an international cross-sectional study of 24-hour movement behaviours in the early years coordinated by the University of Wollongong (https://sunrise-study.com). The study was designed to collect data on movement behaviours among 3–4 year olds in order to provide important benchmarks for surveillance of physical activity and monitoring levels of compliance with the global guidelines, particularly in LMICs where such evidence is limited.[104] Specifically, the SUNRISE International Study broadly aims at (1) determining the prevalence of meeting the 24-hour movement behaviour guidelines among children aged 3–4 years across the participant countries; and (2) determining whether the levels of meeting the guidelines differ by various socioeconomic and demographic backgrounds (e.g., by sex, parental education, residential setting (urban/rural), and country income level).[104]

At the time of writing this thesis, 64 low-, middle-, and high-income countries globally were actively participating in the SUNRISE International Study, including 12 countries from SSA. Participating countries were initially recruited by members of the SUNRISE Leadership Group through their existing collaborations, followed by invitations or expressions of interest.[104] Countries from SSA currently participating in the SUNRISE International Study include three low-, six lower-middle-, and three upper-middle-income countries,[87] as can be seen in *Figure 2-1*. (Note: the author created the map using MapChart [https://www.mapchart.net/], an online tool for creating customisable maps).

A detailed description of the study design and methods have been published in the SUNRISE study protocol.[104] In brief, each participating country implements the protocol in two phases: (1) the pilot study phase to access the acceptability and feasibility of the study protocol from a sex-balanced sample of 100 children aged 3–4 years, with equal numbers (50 each) from urban and rural settings; and (2) the main study phase targeting a sex-balanced sample of 1000 children aged 3–4 years, 500 each from urban and rural settings (*Appendix A*).

Before the start of data collection, country research teams are trained on standardised protocol and data collection by the SUNRISE Coordinating Centre staff based at the University of Wollongong. The Coordinating Centre also loans equipment (e.g., ActiGraph accelerometers, iPads preloaded with Research Electronic Data Capture [REDCap] mobile app, etc.) to participating countries depending on the need and availability.[104]

Since 2018, a number of participating countries have completed the SUNRISE pilot study, but many are yet to begin/complete the main study. One major concern across countries has been funding for the main study. This is because each country's research team is responsible for identifying funding sources to implement the SUNRISE study protocol in their respective countries. Fortunately, Malawi is one of the few countries that successfully obtained funding for an intermediate study between the pilot and main study phases (n=400-500), and subsequently for the full main study (n=1000).

The initial funding from Sir Halley Stewart Trust was obtained at country level and partly funded the work presented in this thesis. While the other funding was obtained from the Canadian Institutes of Health Research (CIHR) in collaboration with three other countries (Brazil, Canada, and India) to expand on the initial work (PI: PhD student [author]; Co-I: JJR). Data collection for the CIHR funded main study is currently underway and not part of this PhD thesis. In addition, a third grant was obtained from the University of Strathclyde/Scottish

Funding Council (SFC)/ International Science Partnerships Fund (ISPF) Scheme to expand on the dissemination and impact activities of evidence from the Sir Halley Stewart Trust funded work in Malawi presented in Chapter 5 (PI: JJR; Research Assistant: PhD student [author]; Coordinator: JK). A full report of the dissemination and impact activities is provided in *Appendix B* of this thesis. (*Note:* The PhD student drafted the first version of the report and designed and formatted the final version in the report. JJR and JK provided significant inputs to the initial draft and approved the final version for submission to the funder).

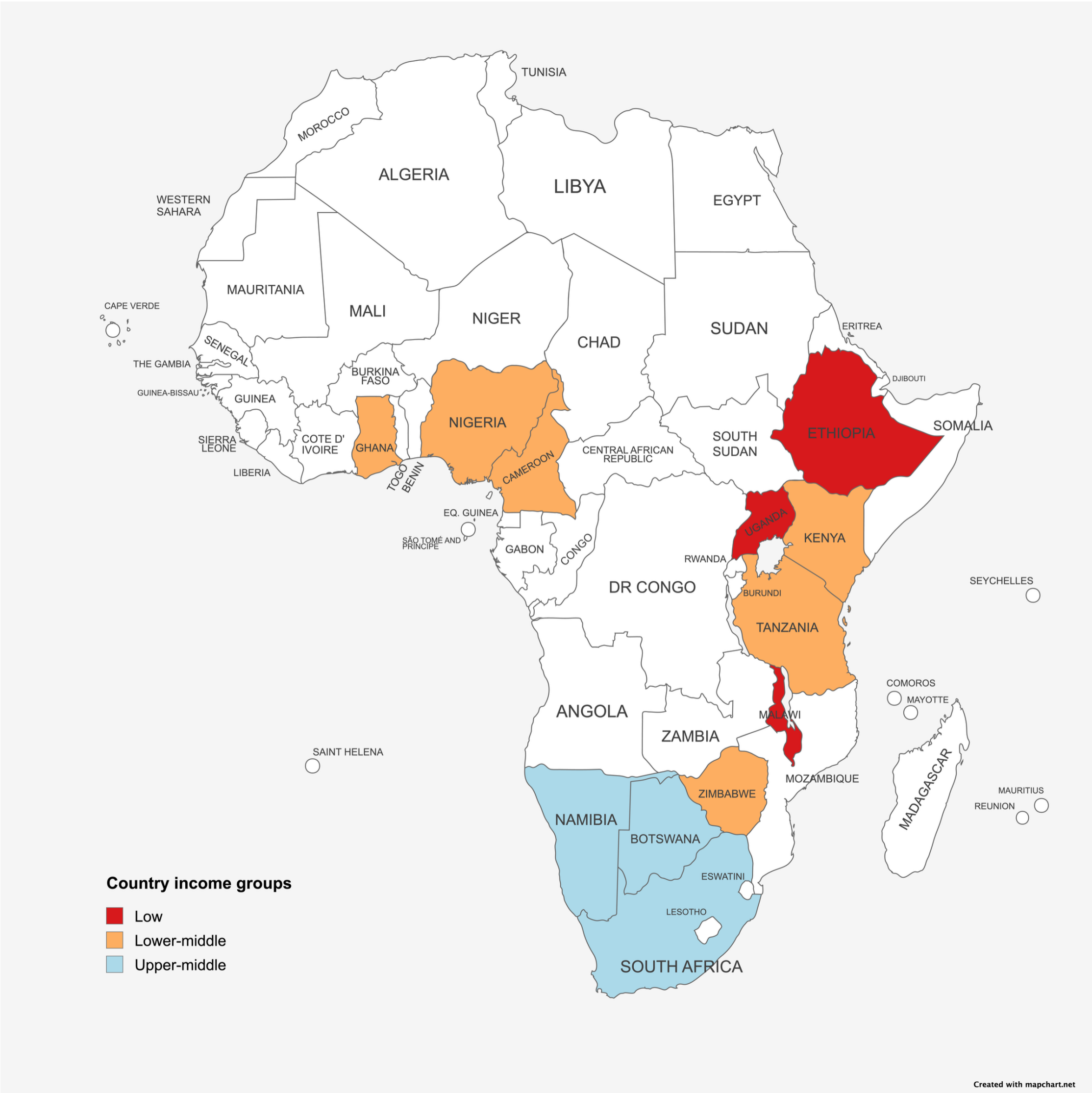

Figure 2-1: Map of Africa showing countries participating in the SUNRISE International Study

Notes: Country income level based on the World Bank classification.[87]

2.6 Research gap

At the time of writing this thesis, only a limited number of studies have been published on the prevalence and correlates of compliance with the global 24-hour movement behaviour guidelines in young children from LMICs, particularly in SSA context as noted above. The dearth of evidence from SSA has previously been confirmed by systematic reviews.[32,85,86,92] Previous evidence was mainly based on small pilot studies in South Africa and Zimbabwe[39,40] until recently when new comparable evidence has emerged from studies published in late 2024.[88,89] However, both the previous and recent studies have been limited in a number of ways. For example, evidence from the South African and Zimbabwean studies is based on data from small SUNRISE pilot studies[39,40] and are both classified as MICs by the World Bank,[87] which may limit generalisability of evidence from such countries to a LIC like Malawi. Chong et al.[88] involved 7017 children from 33 countries globally, including 286 children from SSA countries (Malawi, Tanzania, South Africa, and Zimbabwe), but only 54 of them were from Malawi (based on data from the pilot study prior to this body of work). In addition, Chong et al.[88] reported accelerometry-measured activity (i.e., minutes/day) for assessing physical activity, which may be of limited availability globally due to costs and complexity of measurement as noted earlier,[44,46,53,54,65,71,76] so cheaper and simpler methods would be more useful for surveillance studies globally, particularly in LICs like Malawi. Similarly, the Ethiopian study,[89] the only available large-scale study from a low-income SSA context, reported accelerometry-measured activity (i.e., minutes/day) for assessing compliance with the global physical activity guideline.

As noted above, accelerometry-measured activity may have limited practical utility in surveillance studies due to the complexity of measurement methods and costs of devices.[44,46,53,54,65,71,76] The potential use of accelerometry-measured activity in surveillance studies is significantly hindered in LMICs due to the limited human capacity, funding constraints,[47] and logistical challenges, such as costs associated with shipping and customs clearance and considerable time to get accelerometry equipment across international borders due to shipping delays. While evidence from the Ethiopian study[89] provide valuable insights into movement behaviours among young children from low-income SSA contexts, methods like accelerometry are likely not sustainable for establishing national surveillance systems in resource limited settings in years to come. As such, resource constraints and capacity gaps in these settings may limit consistent use of such methods over time, which will hinder comparison of findings across studies and to determine and monitor future levels of compliance with the guidelines.

Malawi, as in many other LMICs, is about to or is undergoing economic development and rapid urbanisation,[23,105] which is leading lifestyle changes and associated physical activity transition.[21,22] Measuring these lifestyle changes or attempting to modify the physical activity transition through policy interventions urgently requires practical, responsive research, and surveillance methods. This necessitates using simple, low-cost, easy to use, and practical methods like step counting for assessing physical activity and questionnaires for assessing restrained sitting, sedentary screen time, and sleep (if they have evidence of validity and/or reliability within the context that they will be used).

As previously noted, understanding the correlates of compliance with the global movement behaviours in young children is also essential for developing effective policy interventions to improve populations health in line with the Behavioural Epidemiology Framework[90] underpinning the work in this thesis. After validating the measurement methods, the framework also emphasises assessing the prevalence (e.g., of meeting guidelines) and identifying the correlates of health behaviours before designing and evaluating policy interventions.[90] As a result, evidence on meeting the global 24-hour movement behaviour guidelines is urgently needed and must be assessed using feasible and culturally appropriate measurement methods in order to provide accurate prevalence and correlation estimates,[47,82] as well as to inform policies and national surveillance systems for monitoring movement behavioural changes during the transition in Malawi and similar contexts.

2.7 Conclusion to this chapter

In this chapter, the evidence presented emphasises the importance of 24-hour movement behaviours that contribute to the early prevention of NCDs and related obesity in young children. This would in turn contribute to reducing the future burden of NCDs globally, particularly in low-income societies like Malawi that are currently undergoing or will soon be undergoing rapid urbanisation and economic transformation and associated lifestyle changes (physical activity transition). Existing links between NCDs and related overweight/obesity and 24-hour movement behaviours in the early years, including the global guidelines for 3–4 year olds and associated health consequences for meeting the guidelines, are described.

As described in this chapter, there is limited evidence on the prevalence and correlates of meeting the global movement behaviour guidelines from LMICs in SSA, particularly using simple, cheap, practical, and culturally appropriate methods for assessing TPA. Such evidence is needed to inform surveillance systems and policy interventions in resource-limited settings like Malawi and aligns with the Behavioural Epidemiology Framework that underpins the work presented in this thesis. Surveillance initiatives for the global 24-hour movement behaviour guidelines have been discussed and highlighted the gaps in young children and LMICs.

The information and evidence presented in the literature review provide the background and context to the body of work presented in this thesis and highlighted the research gaps. The next three chapters (Chapters 3, 4 and 5) presents evidence from three published studies to address the identified research gaps described in this chapter (Chapter 2).

2.8 Chapter references

1. Calcaterra V, Zuccotti G. Non-Communicable Diseases and Rare Diseases: A Current and Future Public Health Challenge within Pediatrics. Vol. 9, Children. Multidisciplinary Digital Publishing Institute (MDPI); 2022.

2. World Health Organization. Non-communicable diseases [Internet]. Fact Sheet. 2023 [cited 2024 Jul 17]. Available from: https://www.who.int/en/news-room/fact-sheets/detail/noncommunicable-diseases

3. Naghavi M, Ong KL, Aali A, Ababneh HS, Abate YH, Abbafati C, et al. Global burden of 288 causes of death and life expectancy decomposition in 204 countries and territories and 811 subnational locations, 1990–2021: a systematic analysis for the Global Burden of Disease Study 2021. The Lancet. 2024;403(10440):2100–32.

4. Gouda HN, Charlson F, Sorsdahl K, Ahmadzada S, Ferrari AJ, Erskine H, et al. Burden of non-communicable diseases in sub-Saharan Africa, 1990–2017: results from the Global Burden of Disease Study 2017. Lancet Glob Health. 2019 Oct 1;7(10):e1375–87.

5. World Health Organization. Country Disease Outlook: Malawi [Internet]. 2023. Available from: https://www.afro.who.int/sites/default/files/2023-08/Malawi.pdf

6. Balbus JM, Barouki R, Birnbaum LS, Etzel RA, Gluckman SPD, Grandjean P, et al. Early-life prevention of non-communicable diseases. The Lancet [Internet]. 2013;381(9860):3–4. Available from: https://doi.org/10.1016/S0140-6736(12)61609-2

7. NCD Child. Children & Non-Communicable Disease: Global Burden Report 2019 [Internet]. 2019 [cited 2024 Nov 20]. Available from: https://www.ncdchild.org/2019/01/28/children-non-communicable-disease-global-burden-report-2019/

8. Simmonds M, Llewellyn A, Owen CG, Woolacott N. Predicting adult obesity from childhood obesity: A systematic review and meta-analysis. Obesity Reviews. 2016;17(2):95–107.

9. Case A, Fertig A, Paxson C. The lasting impact of childhood health and circumstance. J Health Econ. 2005;24(2):365–89.

10. López-Gil JF, Fabios E, Martín-Calvo N. Meeting the 24-h movement recommendations and its relationship with Mediterranean dietary patterns in early childhood: the SENDO project. Eur J Pediatr [Internet]. 2024;183(5):2365–73. Available from: https://doi.org/10.1007/s00431-024-05472-z

11. Zeng N, Jiang S, Ringer A, Pacheco C, Zheng C, Ye S. Associations Between Combinations of 24-Hour Movement Behaviors and Dietary Outcomes in Children and Adolescents: A Systematic Review. Nutrients . 2024;16(21):1–15.

12. Byambaa A, Jones RA, Chong KH, Dechinjamts O, Jambaldorj B, Okely AD. Clustering of 24-H Movement Behaviours and Its Associations With Eating Behaviours and Adiposity Among Mongolian Preschool Children: A Cross-Sectional Study. Child Care Health Dev. 2025;51(3):1–9.

13. Wang Y, Lim H. The global childhood obesity epidemic and the association between socio-economic status and childhood obesity. International Review of Psychiatry. 2012;24(3):176–88.

14. World Health Organization. Obesity and overweight [Internet]. Fact Sheet. 2024 [cited 2024 Jun 20]. Available from: https://www.who.int/en/news-room/fact-sheets/detail/obesity-and-overweight

15. Diouf A, Adom T, Aouidet A, Hamdouchi A, Joonas N, Loechl C, et al. BMI versus deuterium dilution for establishing childhood obesity prevalence. Bull WHO. 2018;96:772–81.

16. Hills AP, Andersen LB, Byrne NM. Physical activity and obesity in children. Br J Sports Med. 2011;45:866–70.

17. Park MH, Falconer C, Viner RM, Kinra S. The impact of childhood obesity on morbidity and mortality in adulthood: a systematic review. Environ Health Perspect [Internet]. 2012;120(10):1411–7. Available from: http://researchonline.lshtm.ac.uk/27101/

18. Reilly JJ, Kelly J. Long-term impact of overweight and obesity in childhood and adolescence on morbidity and premature mortality in adulthood: Systematic review. Int J Obes [Internet]. 2011;35(7):891–8. Available from: http://dx.doi.org/10.1038/ijo.2010.222

19. Umer A, Kelley GA, Cottrell LE, Giacobbi P, Innes KE, Lilly CL. Childhood obesity and adult cardiovascular disease risk factors: A systematic review with meta-analysis. BMC Public Health. 2017;17(1):1–24.

20. World Health Organization. Report of the commission on ending childhood obesity. Geneva, Switzerland; 2016.

21. Katzmarzyk PT, Mason C. The Physical Activity Transition. J Phys Act Health. 2009;6(3):269–80.

22. Muthuri SK, Wachira LJM, Leblanc AG, Francis CE, Sampson M, Onywera VO, et al. Temporal trends and correlates of physical activity, sedentary behaviour, and physical fitness among school-aged children in Sub-Saharan Africa: A systematic review. Vol. 11, International Journal of Environmental Research and Public Health. 2014. 3327–3359 p.

23. Msyamboza KP, Ngwira B, Dzowela T, Mvula C, Kathyola D, Harries AD, et al. The Burden of Selected Chronic Non-Communicable Diseases and Their Risk Factors in Malawi: Nationwide STEPS Survey. Su Z, editor. PLoS One [Internet]. 2011 May 23 [cited 2025 Mar 29];6(5):e20316. Available from: https://dx.plos.org/10.1371/journal.pone.0020316

24. Rossin-Slater M. Promoting health in early childhood. Future of Children. 2015;25(1):35–64.

25. World Health Organization. World Health Organisation Guidelines for physical activity, sedentary behaviour, and sleep for children under 5 years of age [Internet]. 2019 [cited 2024 Mar 13]. Available from: https://www.who.int/publications/i/item/9789241550536

26. Jones RA, Hinkley T, Okely AD, Salmon J. Tracking physical activity and sedentary behavior in childhood: A systematic review. Am J Prev Med [Internet]. 2013;44(6):651–8. Available from: http://dx.doi.org/10.1016/j.amepre.2013.03.001

27. Wadsworth MEJ, Kuh DJL. Childhood influences on adult health: A review of recent work from the British 1946 national birth cohort study, the MRC National Survey of Health and Development. Paediatr Perinat Epidemiol. 1997;11(1):2–20.

28. Chaput JP, Carson V, Gray CE, Tremblay MS. Importance of all movement behaviors in a 24 hour period for overall health. Int J Environ Res Public Health. 2014;11(12):12575–81.

29. Okely A, Tremblay M, Reilly J, Draper C, Bull F. Physical activity, sedentary behaviour, and sleep: movement behaviours in early life. Lancet Child Adolesc Health. 2018;2:233–5.

30. Kuzik N, Poitras VJ, Tremblay MS, Lee EY, Hunter S, Carson V. Systematic review of the relationships between combinations of movement behaviours and health indicators in the early years (0-4 years). BMC Public Health [Internet]. 2017 Nov 20 [cited 2025 Mar 13];17(S5):849. Available from: https://bmcpublichealth.biomedcentral.com/articles/10.1186/s12889-017-4851-1

31. Rollo S, Antsygina O, Tremblay MS. The whole day matters: Understanding 24-hour movement guideline adherence and relationships with health indicators across the

lifespan. J Sport Health Sci [Internet]. 2020;9(6):493–510. Available from: https://doi.org/10.1016/j.jshs.2020.07.004

32. Feng J, Zheng C, Sit CHP, Reilly JJ, Huang WY. Associations between meeting 24-hour movement guidelines and health in the early years: A systematic review and meta-analysis. J Sports Sci [Internet]. 2021;39(22):2545–57. Available from: https://doi.org/10.1080/02640414.2021.1945183

33. World Health Organization. Physical Activity [Internet]. Fact Sheets. 2024 [cited 2025 Jun 26]. Available from: https://www.who.int/news-room/fact-sheets/detail/physical-activity

34. Okely AD, Ghersi D, Hesketh KD, Santos R, Loughran SP, Cliff DP, et al. A collaborative approach to adopting/ adapting guidelines - The Australian 24-Hour Movement Guidelines for the early years (Birth to 5 years): an integration of physical activity, sedentary behavior, and sleep. BMC Public Health. 2017;17(Suppl 5):896.

35. Tremblay MS, Carson V, Chaput JP, Connor Gorber S, Dinh T, Duggan M, et al. Canadian 24-hour movement guidelines for children and youth: An integration of physical activity, sedentary behaviour, and sleep. Applied Physiology, Nutrition and Metabolism. 2016;41(6):S311–27.

36. Guyatt GH, Oxman AD, Vist G, Kunz R, Brozek J, Alonso-Coello P, et al. GRADE guidelines: 4. Rating the quality of evidence—study limitations (risk of bias). J Clin Epidemiol [Internet]. 2011 Apr [cited 2025 Apr 1];64(4):407–15. Available from: https://www.jclinepi.com/article/S0895-4356(10)00413-0/fulltext

37. Bull FC, Al-Ansari SS, Biddle S, Borodulin K, Buman MP, Cardon G, et al. World Health Organization 2020 guidelines on physical activity and sedentary behaviour. Br J Sports Med [Internet]. 2020 Dec 1 [cited 2025 Feb 4];54(24):1451. Available from: https://pmc.ncbi.nlm.nih.gov/articles/PMC7719906/

38. Reilly JJ, Hughes AR, Janssen X, Hesketh KR, Livingstone S, Hill C, et al. GRADE-ADOLOPMENT Process to Develop 24-Hour Movement Behavior Recommendations and Physical Activity Guidelines for the Under 5s in the United Kingdom, 2019. J Phys Act Health. 2020 Jan 1;17(1):101–8.

39. Draper C, Tomaz S, Cook C, Jugdav S, Ramsammy C, Besharati 5, et al. Understanding the influence of 24-hour movement behaviours on the health and development of preschool children from low-income South African settings: the SUNRISE pilot study. South African Journal of Sports Medicine. 2020;32:1–7.

40. Munambah N, Gretschel P, Muchirahondo F, Chiwaridzo M, Chikwanha T, Kariippanon KE, et al. 24 hour movement behaviours and the health and development of pre-school children from Zimbabwean settings: The SUNRISE pilot study. South African Journal of Sports Medicine. 2021;33(1):1–9.

41. Byambaa A, Dechinjamts O, Jambaldorj B, Jones RA, Chong KH, Okely AD. Prevalence and Health Associations of Meeting the World Health Organization Guidelines for Physical Activity, Sedentary Behavior, and Sleep in Preschool-Aged Children: The SUNRISE Mongolia Pilot and Feasibility Study. J Phys Act Health. 2024;21(3):283–93.

42. Kim T V., Pham TND, Nguyen CLD, Nguyen TTD, Okely AD, Tang HK. Prevalence of physical activity, screen time, and sleep, and associations with adiposity and motor development among preschool-age children in Vietnam: The SUNRISE Vietnam pilot study. Indian J Pediatr [Internet]. 2022;89(2):148–53. Available from: https://doi.org/10.1007/s12098-021-03895-2

43. Loprinzi PD, Cardinal BJ. Measuring children's physical activity and sedentary behaviours. J Exerc Sci Fit [Internet]. 2011;9(1):15–23. Available from: http://dx.doi.org/10.1016/S1728-869X(11)60002-6

44. Adamo KB, Prince SA, Tricco AC, Connor-Gorber S, Tremblay M. A comparison of indirect versus direct measures for assessing physical activity in the pediatric population: A systematic review. International Journal of Pediatric Obesity. 2009;4(1):2–27.

45. Hidding LM, Chinapaw MJM, Poppel MNM Van, Mokkink LB. An Updated Systematic Review of Childhood Physical Activity Questionnaires. Sports Medicine [Internet]. 2018;48(12):2797–842. Available from: https://doi.org/10.1007/s40279-018-0987-0

46. Phillips SM, Summerbell C, Hobbs M, Hesketh KR, Saxena S, Muir C, et al. A systematic review of the validity, reliability, and feasibility of measurement tools used to assess the physical activity and sedentary behaviour of pre-school aged children. International Journal of Behavioral Nutrition and Physical Activity. 2021;18(1):1–28.

47. Reilly J, Aubert S, Brazo-Sayavera J, Liu Y, Cagas J, Tremblay M. Surveillance to improve physical activity of children and adolescents. Bull World Health Organ [Internet]. 2022 Dec 1;100(12):815–24. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9706360/pdf/BLT.22.288569.pdf

48. Davies G, Reilly JJ, Mcgowan AMYJ, Dall PM, Granat MH, Paton JY. Validity, Practical Utility, and Reliability of the activPAL in Preschool Children. Med Sci Sports Exerc. 2012;44(4):761–8.

49. De Craemer M, De Decker E, Santos-Lozano A, Verloigne M, De Bourdeaudhuij I, Deforche B, et al. Validity of the Omron pedometer and the actigraph step count function in preschoolers. J Sci Med Sport [Internet]. 2015;18(3):289–93. Available from: http://dx.doi.org/10.1016/j.jsams.2014.06.001

50. De Decker E, De Craemer M, Santos-Lozano A, Van Cauwenberghe E, De Bourdeaudhuij I, Cardon G. Validity of the ActivPAL™ and the ActiGraph monitors in preschoolers. Med Sci Sports Exerc. 2013;45(10):2002–11.

51. Migueles JH, Cadenas-Sanchez C, Ekelund U, Delisle Nyström C, Mora-Gonzalez J, Löf M, et al. Accelerometer Data Collection and Processing Criteria to Assess Physical Activity and Other Outcomes: A Systematic Review and Practical Considerations. Sports Med [Internet]. 2017 Sep 1 [cited 2025 Feb 12];47(9):1821. Available from: https://pmc.ncbi.nlm.nih.gov/articles/PMC6231536/

52. Bassett DR, Toth LP, LaMunion SR, Crouter SE. Step Counting: A Review of Measurement Considerations and Health-Related Applications. Sports Medicine. 2017;47(7):1303–15.

53. Oliver M, Schofield GM, Kolt GS. Physical Activity in Preschoolers: Understanding Prevalence and Measurement Issues. Sports Medicine [Internet]. 2007;37(12):1045–70. Available from: http://link.springer.com/10.2165/00007256-200737120-00004

54. Oliver M, Schofield GM, Kolt GS, Schluter PJ. Pedometer accuracy in physical activity assessment of preschool children. J Sci Med Sport. 2007;10(5):303–10.

55. De Craemer M, De Decker E, De Bourdeaudhuij I, Verloigne M, Manios Y, Cardon G. The translation of preschoolers' physical activity guidelines into a daily step count target. J Sports Sci [Internet]. 2015;33(10):1051–7. Available from: http://dx.doi.org/10.1080/02640414.2014.981850

56. Gabel L, Proudfoot NA, Obeid J, MacDonald MJ, Bray SR, Cairney J, et al. Step count targets corresponding to new physical activity guidelines for the early years. Med Sci Sports Exerc. 2013;45(2):314–8.

57. Vale S, Trost SG, Duncan MJ, Mota J. Step based physical activity guidelines for preschool-aged children. Prev Med (Baltim) [Internet]. 2015;70:78–82. Available from: http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=emed13&NEWS=N&AN=25445332

58. Guseh JS, Figueroa JF. Evaluating the Health Benefits of Low-Frequency Step-Based Physical Activity-The "Weekend Warrior" Pattern Revisited. JAMA Netw Open. 2023;6(3):e235184.

59. Stamatakis E, Ahmadi M, Murphy MH, Chico TJ, Milton K, Cruz BDP, et al. Journey of a thousand miles: from 'Manpo-Kei' to the first steps-based physical activity recommendations. Br J Sports Med [Internet]. 2023 Oct 1;57(19):1227 LP – 1228. Available from: http://bjsm.bmj.com/content/57/19/1227.abstract

60. Van Stappen V, Van Dyck D, Latomme J, De Bourdeaudhuij I, Moreno L, Socha P, et al. Daily patterns of preschoolers' objectively measured step counts in six european countries: Cross-sectional results from the toybox-study. Int J Environ Res Public Health. 2018;15(2).

61. Sangarapillai T, Hajizadeh M, Daskalopoulou SS, Dasgupta K. Cost-Comparison Analysis of a Physician-Delivered Step-Count Prescription Strategy. CJC Open [Internet]. 2021;3(8):1043–50. Available from: https://doi.org/10.1016/j.cjco.2021.04.009

62. Pagels P, Boldemann C, Raustorp A. Comparison of pedometer and accelerometer measures of physical activity during preschool time on 3- to 5-year-old children. Acta Paediatrica, International Journal of Paediatrics [Internet]. 2011 Jan 1 [cited 2025 Feb 14];100(1):116–20. Available from: https://onlinelibrary.wiley.com/doi/full/10.1111/j.1651-2227.2010.01962.x

63. Sharp CA, Mackintosh KA, Erjavec M, Pascoe DM, Horne PJ. Validity and reliability of the Fitbit Zip as a measure of preschool children's step count. BMJ Open Sport Exerc Med [Internet]. 2017 Oct 11 [cited 2025 Feb 14];3(1):272. Available from: https://bmjopensem.bmj.com/content/3/1/e000272

64. McKee DP, Boreham CAG, Murphy MH, Nevill AM. Validation of the Digiwalker™ pedometer for measuring physical activity in young children. Pediatr Exerc Sci. 2005;17(4):345–52.

65. Cardon G, De Bourdeaudhuij I. Comparison of Pedometer and Accelerometer Measures of Physical Activity in Preschool Children. Pediatr Exerc Sci. 2007;19:205–14.

66. Tanaka C, Tanaka S. Daily Physical activity in Japanese preschool children evaluated by triaxial accelerometry: The relationship between period of engagement in moderate-to-vigorous physical activity and daily step counts. J Physiol Anthropol. 2009;28(6):283–8.

67. Reilly JJ, Janssen X, Cliff DP, Okely AD. Appropriateness of the definition of 'sedentary' in young children: Whole-room calorimetry study. J Sci Med Sport. 2015 Sep 1;18(5):565–8.

68. Tremblay MS, Aubert S, Barnes JD, Saunders TJ, Carson V, Latimer-Cheung AE, et al. Sedentary Behavior Research Network (SBRN) - Terminology Consensus Project

process and outcome. International Journal of Behavioral Nutrition and Physical Activity. 2017;14(1):1–17.

69. Janssen X, Mann KD, Basterfield L, Parkinson KN, Pearce MS, Reilly JK, et al. Development of sedentary behavior across childhood and adolescence: Longitudinal analysis of the Gateshead Millennium Study. International Journal of Behavioral Nutrition and Physical Activity [Internet]. 2016;13(1):1–10. Available from: http://dx.doi.org/10.1186/s12966-016-0413-7

70. Marconcin P, B. Júdice P, Ferrari G, Werneck A, Marques A. Methods of Assessing Sedentary Behaviour. In: Marques A, Gouveia ÉR, editors. Sedentary Behaviour - A Contemporary View [Internet]. IntechOpen; 2021 [cited 2024 Dec 2]. Available from: https://doi.org/10.5772/intechopen.99567

71. Carson V, Draper CE, Okely A, Reilly JJ, Tremblay MS. Future Directions for Movement Behavior Research in the Early Years. J Phys Act Health [Internet]. 2024 Mar 1;21(3):218–21. Available from: https://journals.humankinetics.com/view/journals/jpah/21/3/article-p218.xml

72. Janssen X, Cliff DP. Issues Related to Measuring and Interpreting Objectively Measured Sedentary Behavior Data. Meas Phys Educ Exerc Sci. 2015 Jul 3;19(3):116–24.

73. Byrne R, Terranova CO, Trost SG. Measurement of screen time among young children aged 0–6 years: A systematic review. Obesity Reviews. 2021;22(8):1–28.

74. Meltzer LJ, Williamson AA, Mindell JA. Pediatric sleep health: It matters, and so does how we define it. Vol. 57, Sleep Medicine Reviews. W.B. Saunders Ltd; 2021.

75. Stražišar BG. Sleep Measurement in Children—Are We on the Right Track? Vol. 16, Sleep Medicine Clinics. W.B. Saunders; 2021. p. 649–60.

76. Sadeh A. III. Sleep Assessment Methods. Monogr Soc Res Child Dev. 2015 Mar 22;80(1):33–48.

77. Chaput JP, Gray CE, Poitras VJ, Carson V, Gruber R, Birken CS, et al. Systematic review of the relationships between sleep duration and health indicators in the early years (0-4 years). BMC Public Health. 2017 Nov 20;17.

78. Matricciani L, Paquet C, Galland B, Short M, Olds T. Children’s sleep and health: A meta-review. Vol. 46, Sleep Medicine Reviews. W.B. Saunders Ltd; 2019. p. 136–50.

79. Antsygina O, Rollo S, McRae N, Chaput JP, Tremblay MS. Reliability and validity of instruments containing reported sleep measures among children from birth to <5 years of

age: A systematic review. Sleep Med Rev [Internet]. 2025 Feb 1;79:102023. Available from: https://linkinghub.elsevier.com/retrieve/pii/S1087079224001278

80. Zhang Z, Abdeta C, Chelly MS, Cruz J del P, Germana L, Ghofranipour F, et al. Measurement properties of the SUNRISE Study Parent Questionnaire for assessing sleep and sleep-related family practices. Sleep Health [Internet]. 2025 Jun; Available from: https://linkinghub.elsevier.com/retrieve/pii/S2352721825000828

81. Zhang Z, Abdeta C, Chelly MS, del Pozo Cruz J, Engberg E, Germana L, et al. Measurment properties of the SUNRISE Study Parent Questionnaire for assessing sleep and sleep-related family practices. Sleep Health: Journal of the National Sleep Foundation. 2025;

82. Aubert S, Brazo-Sayavera J, González SA, Janssen I, Manyanga T, Oyeyemi AL, et al. Global prevalence of physical activity for children and adolescents; inconsistencies, research gaps, and recommendations: a narrative review. International Journal of Behavioral Nutrition and Physical Activity. 2021;18(1):1–11.

83. Aubert S, Barnes JD, Demchenko I, Hawthorne M, Abdeta C, Nader PA, et al. Global Matrix 4.0 Physical Activity Report Card Grades for Children and Adolescents: Results and Analyses From 57 Countries. J Phys Act Health. 2022;19(11):700–28.

84. Reilly JJ, Andrew R, Abdeta C, Azevedo LB, Farias NA, Barak S, et al. Improving National and International Surveillance of Movement Behaviours in Childhood and Adolescence: An International Modified Delphi Study. Sports Medicine [Internet]. 2025 Jan 3;55(1):203–19. Available from: https://link.springer.com/article/10.1007/s40279-024-02104-2

85. Tapia-Serrano MA, Sevil-Serrano J, Sánchez-Miguel PA, López-Gil JF, Tremblay MS, García-Hermoso A. Prevalence of meeting 24-hour movement guidelines from pre-school to adolescence: A systematic review and meta-analysis including 387,437 participants and 23 countries. J Sport Health Sci. 2022;11(4):427–37.

86. Nusurupia J, J. RJ, Xanne J. Pre-school children's compliance with the WHO 24-hour movement behaviour guidelines: a systematic review of Sub-Saharan African studies. African Journal for Physical Activity and Health Sciences (AJPHES) [Internet]. 2020 Dec 1;26(4):345–59. Available from: https://doi.org/10.10520/ejc-ajpherd1-v26-n4-a2

87. The World Bank. World Bank country and lending groups [Internet]. [cited 2024 Dec 12]. Available from: https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups

88. Chong KH, Suesse T, Cross PL, Ryan ST, Aadland E, Aoko O, et al. Pooled Analysis of Physical Activity, Sedentary Behavior, and Sleep Among Children From 33 Countries. JAMA Pediatr [Internet]. 2024 Nov 1;178(11):1199. Available from: https://jamanetwork.com/journals/jamapediatrics/fullarticle/2824006

89. Abdeta C, Cliff D, Kariippanon K, Deksisa A, Garoma S, Tesfaye D, et al. Adherence to the WHO physical activity, screen time and sleep guidelines and associations with socio-demographic factors among Ethiopian preschool children: The SUNRISE study. Journal of Activity, Sedentary and Sleep Behaviors [Internet]. 2024 Sep 11;3(1):22. Available from: https://jassb.biomedcentral.com/articles/10.1186/s44167-024-00060-w

90. Sallis JF, Owen N, Fotheringham MJ. Behavioral epidemiology: A systematic framework to classify phases of research on health promotion and disease prevention. Annals of Behavioral Medicine [Internet]. 2000;22(4):294–8. Available from: https://academic.oup.com/abm/article/22/4/294/4633687

91. Sallis JF, Owen N, Fisher EB. Ecological models of health behaviour. In: Glanz K, Rimer BK, Viswanath K., editors. Health behavior and health education: theory, research, and practice. 4th ed. San Francisco; 2008. p. 465–85.

92. Arts J, Drotos E, Singh AS, Chinapaw MJM, Altenburg TM, Gubbels JS. Correlates of Physical Activity in 0- to 5-year-olds: A Systematic Umbrella Review and Consultation of International Researchers. Sports Medicine [Internet]. 2023;53(1):215–40. Available from: https://doi.org/10.1007/s40279-022-01761-5

93. Kariippanon KE, Chong KH, Janssen X, Tomaz SA, Ribeiro EHC, Munambah N, et al. Levels and Correlates of Objectively Measured Sedentary Behavior in Young Children: SUNRISE Study Results from 19 Countries. Med Sci Sports Exerc. 2022;54(7):1123–30.

94. United Nations Development Programme. Human Development Index (HDI) [Internet]. [cited 2025 Apr 12]. Available from: https://hdr.undp.org/data-center/human-development-index#/indicies/HDI

95. Nusurupia JJ, Germana LH, Wickramasinghe P, Tang HK, Munambah N, Hossain MS, et al. Urban Versus Rural Differences in Meeting 24-h Movement Behaviour Guidelines Among 3–4-Year-Olds: An Analysis of SUNRISE Pilot Study Data From 10 Low- and Middle-Income Countries. Child Care Health Dev. 2024 Nov 1;50(6).

96. World Health Organization. Public health surveillance [Internet]. [cited 2024 Nov 5]. Available from: https://www.afro.who.int/health-topics/public-health-surveillance

97. World Health Organization. WHO guidelines on ethical issues in public health surveillance [Internet]. Geneva; 2017 [cited 2024 Nov 5]. Available from: https://www.who.int/publications/i/item/who-guidelines-on-ethical-issues-in-public-health-surveillance

98. World Health Organization. Global action plan on physical activity 2018–2030: more active people for a healthier world [Internet]. Geneva; 2018. Available from: https://www.who.int/publications/i/item/9789241514187

99. Bischops AC, Radev ST, Köthe U, Chen S, Geldsetzer P, Sarker M, et al. Data Resource Profile: The Global School-based Student Health Survey - Behavioural risk and protective factors among adolescents. Int J Epidemiol. 2023 Apr 1;52(2):E102–9.

100. Moor I, Winter K, Bilz L, Bucksch J, Finne E, John N, et al. The 2017/18 Health Behaviour in School-aged Children (HBSC) study - Methodology of the World Health Organization’s child and adolescent health study. Journal of health monitoring [Internet]. 2020 Sep;5(3):88–102. Available from: http://www.ncbi.nlm.nih.gov/pubmed/35146275

101. Tremblay MS, Barnes JD, Demchenko I, Gonzalez SA, Brazo-Sayavera J, Kalinowski J, et al. Active Healthy Kids Global Alliance Global Matrix 4.0—A Resource for Physical Activity Researchers. J Phys Act Health. 2022 Nov 1;19(11):693–9.

102. MRC Epidemiology Unit. International Children’s Accelerometry Database [Internet]. [cited 2024 Dec 5]. Available from: https://www.mrc-epid.cam.ac.uk/research/studies/icad/

103. Bonita R, de Courten M, Dwyer T, Jamrozik K, Winkelmann R. Surveillance of risk factors for noncommunicable diseases: The WHO STEPwise approach. Summary. Geneva: World Health Organization; 2001.

104. Okely AD, Reilly JJ, Tremblay MS, Kariippanon KE, Draper CE, El Hamdouchi A, et al. Cross-sectional examination of 24-hour movement behaviours among 3- and 4-year-old children in urban and rural settings in low-income, middle-income and high-income countries: the SUNRISE study protocol. BMJ Open [Internet]. 2021 Oct;11(10):e049267. Available from: https://bmjopen.bmj.com/lookup/doi/10.1136/bmjopen-2021-049267

105. Government of Malawi. Malawi’s vision: An inclusively wealthy and self-reliant nation [Internet]. Lilongwe; 2020 [cited 2024 Mar 3]. Available from: https://npc.mw/wp-content/uploads/2021/02/MW2063-VISION-FINAL.pdf

Chapter 3: Validity of low-cost measures for global surveillance of physical activity in pre-school children: the SUNRISE validation study

3.1 Preface

This chapter provides an overview of the pilot phases of the SUNRISE International Study[26] and the validation of three existing step count thresholds for assessing the global TPA guideline among 3–4 year olds. As previously noted, validating measures is the first step for developing public health interventions to improve the population's health. This chapter includes an article "Validity of low-cost measures for global surveillance of physical activity in pre-school children: The SUNRISE validation study" that was published in the *Journal of Science and Medicine in Sports.*

3.1.1 Chapter introduction and rationale

The first two chapters of this thesis discussed the background, aims, and literature to provide the context of this research. The burden of movement behaviour-related NCDs is increasing globally, particularly in LMICs. The first step in developing evidence-based interventions to tackle the global burden and associated obesity is establishing valid and feasible methods for assessing health behaviours in line with the Behavioural Epidemiology Framework.[2] Valid, low-cost, and culturally appropriate methods are required for assessing physical activity in resource-limited settings, like LMICs,[3] to ensure equity in movement behaviours research globally.[4] Yet, no studies have assessed feasible measurement methods for large-scale movement behaviour surveillance in early childhood globally, including in LMICs, as earlier noted.

To address this research gap, this chapter aimed to establish the cultural appropriateness and validity of low-cost measurement methods of assessing the global TPA guideline in 3–4 year olds in Malawi. Specifically, it focused on validating the widely used parent reports and the emerging step counting method against accelerometry. Given the lack of evidence from Malawi, the chapter presents evidence based on secondary analysis of cross-sectional data from two pilot phases of the SUNRISE International Study.[1] A detailed description of the methods used is included in the published article provided later in this chapter. However, the following section expands on the methods in the published work by providing additional information about the first two pilot phases of the SUNRISE International Study.[1]

3.1.2 About the pilot phases of the SUNRISE International Study

As previously noted, the SUNRISE International Study is a collaborative cross-sectional study of movement behaviours in the early years (3–4 years). This global surveillance initiative was designed in response to the dearth of evidence on compliance with the global movement behaviour guidelines in young children globally, particularly in LMICs.[1] At the time of writing this thesis, over 60 countries were actively participating in the SUNRISE International Study. Participating countries are required to initially implement a pilot study to access the feasibility and acceptability of the study protocol before the main study. To date, the SUNRISE Pilot study has been implemented in three distinct phases.[1] The first two pilot phases were implemented between March 2018 and September 2020 and involved 20 countries. All countries that joined later have and are implementing the third pilot phase protocol that is also used for the main study.[1]

The phased implementation was being done to allow modification to the protocol based on feedback from participating parents, early childhood education and care (ECEC) centre staff, and country research teams.[1] Notably, data on the 24-hour movement behaviours (physical activity, sedentary time, and sleep) during the first two phases were collected concurrently using ActiGraph, *activ*PAL™, and Actical accelerometers. However, the use of *activ*PAL™ accelerometers was stopped in some countries during Phase 2 due to reports of minor skin irritations.[1] Consequently, all countries implementing Phase 3 pilot protocol and the main study have exclusively been using ActiGraph accelerometers for assessing 24-hour movement behaviours in participating children.[1] Accelerometry data collection was complemented by parent reports of the time their child spent in specific behaviours, collected using the SUNRISE parent questionnaire (*Appendix C*). Among others, the questionnaire is used to collect data on sociodemographic variables and child's restrained sitting, sedentary screen time, and sleep duration. Child's anthropometric measurements (height and weight) are also taken during data collect. In addition, centre questionnaire (*Appendix D*) is used to record information about participating country name, date and period of data collection at the centre that is used to determined season of the year, and the location of the ECEC centre that is used to determine child's residential setting (urban/rural).

Before the start of data collection, participating country research teams are trained by the SUNRISE Coordinating Centre staff on standardised SUNRISE protocol. The Coordinating Centre staff also provide technical support throughout the study implementation, including conducting regular data quality checks during data collection. In addition, the Coordinating Centre manages and provides secure storage for all participating country data. Pooled anonymised and cleaned data from the pilot phases is available on request from the SUNRISE Coordinating Centre. The SUNRISE International Study protocol was reviewed and approved by the Human Research Ethics Committee at the University of Wollongong (Coordinating Centre reference number: 2018/044; *Appendix E*) and by relevant ethics committees in each participating.

Data for the pilot phases 1 and 2 were obtained from the Coordinating Centre, which were used for the two secondary analyses presented in this and the next chapter (Chapter 4). Additionally, it was not possible to collect primary data in Malawi at the start of the work presented in this thesis due to the COVID-19 related restrictions and funding constraints. Funding from the Sir Halley Stewart Trust was secured later in 2021 but only became available in early 2022.

3.1.3 Data management and analysis methods

As noted above, data used for the secondary analysis presented in this chapter were obtained from the University of Wollongong. The raw data file was shared in Excel format, and it comprised dataset and data dictionary sheets. The data dictionary described each variable in the dataset and helped to identify the variables relevant to our analysis. The dataset sheet contained collated data for 1325 children who participated in pilot phases 1 and 2 of the SUNRISE International Study. The data included records from parent reported questionnaire (i.e., sociodemographic information), anthropometry (height and weight), and accelerometry measurements from ActiGraph and *activ*PAL™. The dataset contained 955 records for children who wore *activ*PAL™ for physical activity measurement, which was the main focus of our analysis.

Data were imported into Stata/IC v.16.1 for Mac (StataCorp, College Station, Texas, USA), a statistical software package that was used for all data cleaning and analyses. The data dictionary was used to identify all variables relevant to our analysis, and records for children with *activ*PAL™ data were extracted for further cleaning and analysis. Data cleaning included converting string variables to numerical variables (e.g., sex was recorded as boy or girl and converted to numerical values 1 and 2, respectively), re-coding variables (e.g., age was recorded as a continuous variable and this was re-coded to a variable with two categories [3- and 4-year olds] that was used for analysis), and creating a new variable (e.g., for country income group, including low-, middle-, and high-income countries). All data were checked for missing values and a 'complete case analysis' method was used for handing missing data during data analysis (see *Section 5.1.2.7* of Chapter 5 for details on handling missing data).

Data analysis methods used in this chapter included both descriptive and inferential statistical analyses. A detailed description of these methods is provided in the published article presented later in this chapter (*Section 3.3*). In summary, descriptive analyses were performed to describe characteristics of participants, and summary statistics were presented as means and standard deviations for continuous variables that were normally distributed, and frequencies and percentages for categorical variables. The validity of parent reported child's habitual TPA against *activ*PAL™-measured TPA was assessed using Spearman's rank-order correlation, Bland–Altman plots, and Kappa statistics, while the validity of three existing step count thresholds[7–9] were assessed using Receiver Operating Characteristic Area Under the Curve analysis. As appropriate, results from the validation analyses were presented with associated p-values and 95% confidence intervals. Statistical significance was determined at 5% level (i.e., p<0.05).

3.2 Chapter significance and contribution to research

This study establishes the validity of different measurement approaches for assessing compliance with physical activity guidelines in preschool children aged 3-4 years from diverse global settings. The findings have important implications for population-based physical activity surveillance globally, particularly in LMICs. Physical activity surveillance systems globally require the use of valid, low-cost, and culturally appropriate methods to monitor compliance with global guidelines.[10] However, capacity gaps and resource constraints in many LMICs like Malawi could limit the use of expensive accelerometry-based methods that require specialised expertise.[11–14]

The significance of this study lies in demonstrating that step counting, with a threshold of 11,500 steps/day, provides a viable alternative to both parent reports and more expensive accelerometry approaches (e.g., by potentially using devices like pedometers which are significantly cheaper than research-grade accelerometers). In line with the Behavioural Epidemiology Framework,[15] this validated threshold offers a practical, low-cost option for use in surveillance studies globally, including in resource-limited settings.

This chapter establishes the rationale for the subsequent work in Chapter 4, which utilised validated step count threshold to examine the prevalence and correlates of meeting the global TPA guideline in a geographically and culturally diverse sample of 3- and 4-year-olds globally, including LMICs. Additionally, it provides the methodological basis for generating evidence using feasible measurement methods for assessing 24-hour movement behaviours in young children from low-income SSA contexts in Chapter 5.

3.3 Published article

As previously mentioned, this article was published as original research in the *Journal of Science and Medicine in Sports* in October 2022. The final, proof-corrected Microsoft Word version of the manuscript for the published article is presented in the following section of this chapter for readability and the PDF version of published format is available in *Appendix F-1* of this thesis.

Suggested citation

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Author contributions

I am the primary (first) author of this article. In consultation with and inputs from my supervisors (JJR and XJ), I conceived and designed this study. XJ obtained data from the SUNRISE Coordinating Centre based at the University of Wollongong. I cleaned and analysed the data, drafted the first version of the manuscript and revised it based on inputs from all authors, submitted the final version of the manuscript for publication, and addressed reviewer comments in consultation with my supervisors. All other authors contributed to data acquisition, and provided critical inputs to the drafted manuscript. All authors approved the final version before submission in line with the International Committee of Medical Journal Editors authorship guidelines (https://www.icmje.org/recommendations/browse/roles-and-responsibilities/defining-the-role-of-authors-and-contributors.html).

Supplementary materials

Supplementary material mentioned in this article is presented in *Appendix F-2* of this thesis.

Title: Validity of low-cost measures for global surveillance of physical activity in pre-school children: the SUNRISE validation study

Authors:

Tawonga W. Mwase-Vuma [a,b], Xanne Janssen [a], Anthony D. Okely [c], Mark S. Tremblay [d,e,f], Catherine E. Draper [g], Alex Antonio Florindo [h], Chiaki Tanaka [i], Denise Koh [j], Guan Hongyan [k], Hong K. Tang [l], Kar Hau Chong [c], Marie Löf [m], Mohammad Sorowar Hossain [n], Penny Cross [c], P. W. Prasad Chathurangana[o], John J. Reilly[a]

Institution and affiliations:

a. School of Psychological Sciences and Health, University of Strathclyde, Glasgow, UK
b. Centre for Social Research, University of Malawi, Zomba, Malawi
c. Early Start, Faculty of the Arts, Social Sciences and Humanities, University of Wollongong, Wollongong, New South Wales, Australia
d. CHEO Research Institute, Ottawa, Ontario, Canada
e. Department of Pediatrics, University of Ottawa, Ottawa, Ontario, Canada
f. Department of Health Sciences, Carleton University, Ontario, Canada
g. SAMRC/Wits Developmental Pathways for Health Research Unit, University of the Witwatersrand, Johannesburg, South Africa
h. School of Arts, Sciences, and Humanities, University of Sao Paulo, Sao Paulo, Brazil
i. Department of Human Nutrition, Tokyo Kasei Gakuin University, Tokyo, Japan
j. Centre of Community Education & Wellbeing, Faculty of Education, Universiti Kebangsaan Malaysia, Bangi, Malaysia
k. Department of Early Childhood Development, Capital Institute of Pediatrics, Beijing, China
l. Department of Epidemiology, Faculty of Public Health, Pham Ngoc Thach University of Medicine, Ho Chi Minh City, Vietnam
m. Department of Biosciences and Nutrition, Karolinska Institutet, Sweden
n. Department of Emerging and Neglected Diseases, Biomedical Research Foundation, Dhaka, Bangladesh
o. Department of Paediatrics, Faculty of Medicine, University of Colombo, Colombo, Sri Lanka

Corresponding author:

Tawonga Mwase-Vuma, Centre for Social Research, University of Malawi, P.O. Box 280, Zomba Malawi

Email: tawonga.mwase-vuma@strath.ac.uk

ORCID: 0000-0002-0189-1488

Twitter: @Taomwase

Abstract

Objectives: To validate parent-reported child habitual total physical activity against accelerometry and three existing step-count thresholds for classifying 3 h/day of total physical activity in pre-schoolers from 13 culturally and geographically diverse countries.

Design: Cross-sectional validation study.

Methods: We used data involving 3- and 4-year-olds from 13 middle- and high-income countries who participated in the SUNRISE study. We used Spearman's rank-order correlation, Bland–Altman plots, and Kappa statistics to validate parent-reported child habitual total physical activity against activPAL™-measured total physical activity over 3 days. Additionally, we used Receiver Operating Characteristic Area Under the Curve analysis to validate existing step-count thresholds (Gabel, Vale, and De Craemer) using step-counts derived from activPAL™.

Results: Of the 352 pre-schoolers, 49.1% were girls. There was a very weak but significant positive correlation and slight agreement between parent-reported total physical activity and accelerometer-measured total physical activity (r: 0.140; p=0.009; Kappa: 0.030). Parents overestimated their child's total physical activity compared to accelerometry (mean bias: 69 min/day; standard deviation: 126; 95% limits of agreement: −179, 316). Of the three step-count thresholds tested, the De Craemer threshold of 11,500 steps/day provided excellent classification of meeting the total physical activity guideline as measured by accelerometry (area under the ROC curve: 0.945; 95% confidence interval: 0.928, 0.961; sensitivity: 100.0%; specificity: 88.9%).

Conclusions: Parent reports may have limited validity for assessing pre-schoolers' level of total physical activity. Step-counting is a promising alternative – low-cost global surveillance initiatives could potentially use pedometers for assessing compliance with the physical activity guideline in early childhood.

Keywords: Measurement, Physical activity, Accelerometry, Parent reports, Pedometer, Child

Introduction

In 2016, the World Health Organization (WHO) recommended promotion of physical activity in early childhood as a critical component of the global obesity prevention agenda.[1] Consequently in 2019, the WHO developed the first global guidelines for physical activity, sedentary behaviours and sleep for under 5s to tackle the obesity pandemic and improve children's health and development.[2] Among pre-schoolers (3-4 years), the WHO recommends daily total physical activity (TPA) of at least 180 minutes including 60 minutes of moderate- to vigorous-intensity physical activity (MVPA). Despite the publication of these guidelines in 2019,[2] there is currently no systematic global surveillance of physical activity at this age group across the globe[3] partly due to practical issues like budget limitations and uncertainty over the validity and cultural appropriateness of physical activity surveillance measurements globally. As such, there is a need for a relatively simple, low-cost and sustainable method of surveillance which has criterion validity (against accelerometry) to assess compliance with the guidelines and allow comparisons across studies, cultures, populations, and countries. One obvious option on cost grounds is proxy reports from parents,[4–6] but there is no geographically and culturally validated questionnaire for global surveillance of physical activity in the early years (under 5s) to date.[3]

So far, only four studies[6–9] have validated parent-reported physical activity against the commonly used criterion measure of accelerometry in children under 5 years: Bacardi-Gascón et al.[8] used light physical activity (LPA), moderate physical activity (MPA), and MVPA; Bingham et al.[9] used MVPA; and the remaining two studies evaluated parent-reported TPA against accelerometer-measured TPA (LPA+MVPA) among 3-5 years old Australian[7] and 4-70 months old Canadian[6] children. However, all of these validation studies[6–9] are limited to a single geographical location and in high income countries (HICs). To the best of our knowledge, there have been no attempts to validate parent-reported TPA against *activ*PAL™ measured TPA (the criterion method) in 3- to 4-year-olds across various countries. The *activ*PAL™ is one of the most commonly used research-grade accelerometers for objective measurement of physical activity, and has been validated for measurement of TPA against direct observation in this age group.[10]

Another simple low-cost global alternative to parent reports for global public health surveillance of TPA is step-counting. Over the last decade several studies have developed step-counting thresholds to classify 3 hours of TPA in pre-schoolers.[11–13] However, previous studies proposed widely varying step-count thresholds derived from the ActiGraph accelerometers which were equivalent to 3 hours daily TPA[11–13]: Gabel et al.[11] recommended a step-count threshold of 6,000 steps/day; Vale et al.[12] suggested 9,000 steps/day; and De Craemer at al.[13] suggested 11,500 steps/day. To date, it remains unclear which of these step-count thresholds provides the most accurate measure which might be suitable to use for global surveillance of TPA in preschool-aged children and whether these thresholds are valid when using different step-count devices and placements.

Therefore, in order to help develop relatively simple methods of physical activity assessment suitable for global public health surveillance in pre-schoolers in future, the aims of our study were to (a) validate parent-reported habitual TPA against *activ*PAL™ measured habitual TPA (calculated as total time spent stepping min/day) in pre-schoolers from geographically and culturally diverse countries, and (b) cross-validate existing step-count thresholds for determining habitual TPA against *activ*PAL™ measured TPA. Given the diversity of our sample, we also explored differences in validation outcomes between parent-reported and accelerometer-measured TPA across the socio-demographic characteristics of study participants.

Methods

This study was a secondary analysis of *activ*PAL™ (PAL Technologies Ltd, Glasgow, UK) data collected as part of the first and second pilot phases of the SUNRISE Study (https://sunrise-study.com/), an international cross-sectional study of movement behaviours in the early years.[4] The SUNRISE study is being conducted in 43 high-, middle- and low-income countries. Over 2,500 children aged 2-6 years from 23 countries have completed the pilot phase of the study, with *activ*PAL™ data available for 955 children from 17 countries. Data are de-identified and available on request from the SUNRISE Coordinating Centre based at the University of Wollongong (UOW), Australia. The SUNRISE study protocol was reviewed and approved by Human Research Ethics Committee at the UOW (2018/044) and ethics committees in each participating country; all parents of participating children gave informed consent.

A total of 352 pre-schoolers aged 3-4 years from 13 countries who participated in the pilot phases 1 and 2 of the SUNRISE Study comprised the sample for our validation study. Participants were included in the current study if: (i) they had both *activ*PAL™ and parent-reported habitual TPA data; (ii) they had three valid days of *activ*PAL™ measurement (i.e., a valid day was defined as having 24-hours of data), which is appropriate to measure usual level of TPA[14]; and (iii) they were aged 3.0 to <5.0 years. One participant was excluded because the parent-reported level of child physical activity was recorded as zero.

No significant differences in participant characteristics were found between those included and excluded in our study, except for a higher percentage of urban children that have been included in this validation study (59% vs 44%). Since future global surveillance of physical activity in children will need to take place in diverse settings, a range of countries (Australia, Bangladesh, Brazil, China, Hong Kong, Indonesia, Japan, Malaysia, South Africa, South Korea, Sri Lanka, Sweden, and Vietnam) and income levels (lower-middle, upper-middle, and high-income countries) were represented in our study.

Habitual TPA by accelerometry was assessed using *activ*PAL™, an activity monitor worn on the thigh with an accelerometer to record time spent sitting/lying, moving/stepping and standing in 15-second epochs.[15] TPA was calculated as the total time spent stepping per day (min/day). The *activ*PAL™ has been validated against direct observation of physical activity for measurement of TPA in 3-4 year-olds, with high sensitivity and specificity for measurement of TPA relative to direct observation and no significant bias in measurement of TPA.[10] Children were asked to continuously wear the device on the right anterior thigh, midway between the hip and the knee in the midline, for 3-5 five days.[4] This allowed collection of three full days of data (3 x 24-hour period) on TPA. Based on the 2019 WHO Global Guidelines for TPA in children aged 3-4 years,[2] participants were classified as meeting the guideline if they spent an average of at least of 180 min/day in TPA.

Habitual TPA by parent reports was assessed using a parent questionnaire completed by self-administration, or interviewer-administered when necessary, for example, where literacy posed challenges.[4] Questions were developed based on available physical activity, sedentary behaviour, and sleep guidelines for the early years.[16] Parents were asked: "On a 24-hour period in the past week, how much time did the 3- to 4-year-old child who is participating in this study spend in a variety of physical activities, spread throughout the day? For example: active play, running, playing with balls, moving to music/dancing, swimming, riding a scooter/tricycle/bike." Parent reports were recorded in hours and minutes and were converted to min/day to calculate parent-reported habitual TPA. This was used to classify participants as meeting the physical activity guideline if they spent an average of at least 180 min/day in TPA.

Habitual number of steps taken was assessed using *activ*PAL™ accelerometers. As noted earlier, the *activ*PAL™ records time spent sitting/lying, moving/stepping and standing in 15-second epochs,[15] and it has been validated for measurement of step-counting in older children aged 9-10 years.[17] Since children were asked to wear the device continuously for 3-5 days, its stepping function allowed collection of three full days of data (3 x 24-hour period) on total step-counts. These were used to classify participants as either meeting or not meeting the 180 min/day of TPA in three ways based on the three step-count thresholds in the literature[11–13]: ≥6,000 steps/day[11]; ≥9,000 steps/day[12]; and ≥11,500 steps/day.[13]

Socio-demographic information of participating children were recorded based on a modified version of the WHO STEPS Survey.[18] Parents reported their child's date of birth (or age in complete years if date of birth was unknown) and this was used to determine the child's age in years and months. Parents reported their child's sex as either boy or girl. Highest level of education completed by the parent or other member of the household was recorded based on each participating country's educational classification and this was then grouped into two categories due to varying educational classifications between countries: low (secondary/high school or below) or high (tertiary education or above) education. Country income level was classified based on the World Bank classification (https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups): lower-middle, upper-middle, and high-income country. However, we treated the two categories for middle-income country (MIC) as one category (i.e., MIC) in our analyses due to fewer children (n=47) from lower-middle income countries. Child's residential area was recorded as either urban or rural based on the location of the Early Childhood Education and Care (ECEC) centre or community where children were recruited to participate in the SUNRISE study.[4]

Descriptive analyses were performed to describe characteristics of participants and presented as means, standard deviations (SD), frequency, and percentage (%). We assessed the validity of the parent-reported level of child TPA in meeting the WHO TPA guideline for pre-schoolers in four ways. First, we used Spearman's rank-order correlation (*r*) to determine the ability of the questionnaire to correctly rank order children by time spent in TPA (min/day) measured by *activ*PAL™. The strength of the correlations were classed as: 0.00–0.19 'very weak'; 0.20–0.39 'weak'; 0.40–0.59 'moderate', 0.60–0.79 'strong'; 0.80–1.0 'very strong'.[19] Our sample was powered to detect a correlation of *r*: 0.1489 at 80% power and 0.05 significance level. Secondly, we used Kappa statistics to assess the ability of parent reports to place individuals in tertiles of habitual TPA measured by accelerometry: strength of agreement was classified using Landis and Koch: <0.00 'poor agreement'; 0.00–0.20 'slight agreement'; 0.21–0.40 'fair agreement'; 0.41–0.60 'moderate agreement'; 0.61–0.80 'substantial agreement'; and 0.81–1.00 'almost perfect agreement'.[20] We also assessed the ability of the questionnaire results to classify participants as meeting (sensitivity) or not meeting (specificity) the TPA guideline by reporting percentage agreement. Sub-group analyses were conducted by the various socio-demographic characteristics (i.e., sex, education class, residential area, and country income level) to explore differences in correlation and classification accuracy between parent-reported and accelerometer-measured TPA. Finally, we used Bland–Altman plots to evaluate bias between parent-reported habitual TPA measure and accelerometry by plotting the difference between the two methods against accelerometry (the criterion method).[21] We also used Bland–Altman plots to calculate 'limits of agreement' (LOA, i.e., mean bias ±1.96 SD). Additionally, we used Pearson's correlation to test for systematic bias between the difference and the criterion method.

We validated the three proposed step-count thresholds by calculating sensitivity, specificity, and area under the receiver operating characteristic curve (ROC-AUC) for Gabel, Vale & De Craemer step-count thresholds using steps derived from *activ*PAL™.[11–13] The ROC-AUC provides a measure of classification accuracy by graphically plotting the *y*-axis as true positive rate (sensitivity) and *x*-axis as false positive rate (1 – specificity). ROC-AUC values were defined as excellent (0.9–1.0), good (0.8–0.9), fair (0.7–0.8), or poor (<0.7).[22] Statistical significance was determined at 5%. All analyses were performed in Stata/IC v.16.1 for Mac

(StataCorp, College Station, Texas, USA) except for ROC-AUC which was performed using SPSS v.27 for Mac (IBM Corp, Armonk, NY, USA).

Results

We included 352 pre-schoolers aged 3.0-4.9 years from 13 countries: 3 lower-middle, 5 upper-middle, 5 high-income countries (Supplementary Table A available in *Appendix F-2* of this thesis). Descriptive characteristics of participants are presented in *Table 3-1*. The proportions of boys and girls included in the current study were similar. A slight majority (59.1%) lived in urban areas and over two-thirds (67.0%) were from lower- and upper-MICs. The mean age was 4.4 (SD: 0.3) years. Children accumulated an average of 119 (SD: 32) min/day of TPA and accumulated an average of 8,784 steps (SD: 2,548) as measured by the *activ*PAL™. Using the parent reports, children achieved an average of 188 (SD: 127) min/day of TPA.

Table 3-1: Characteristics of study participants (as frequency and percentage unless specified)

	Frequency	Percent
Sex		
Boys	179	50.9
Girls	173	49.1
Education class		
High	183	52.0
Low	165	46.9
Missing	*4*	*1.1*
Residential area		
Urban	208	59.1
Rural	144	40.9
Country income level [a]		
HICs	116	33.0
MICs	236	67.0
	Frequency	**Mean (SD)**
Age, years	352	4.4 (0.3)
Accelerometer total physical activity, min/day	352	118.9 (31.7)
Parent-reported total physical activity, min/day	352	187.6 (126.9)
Total step-count, steps/day	352	8,783.6 (2,548.2)

Note: HIC = High-income countries; MICs = Middle-income countries

[a] denotes derived variable based on World Bank classification

Table 3-2 shows rank-order correlations between parent-reported against accelerometer-measured TPA across various demographic characteristics of participants. There was a very weak but statistically significant positive correlation between parent-reported and accelerometer-measured TPA (*r*: 0.140; p=0.009). When stratified by various demographic characteristics, correlations ranged from very weak to weak (*r*: 0.034–0.233). Correlations were statistically significant for boys, participants from highly educated families, and those from MICs.

Overall, there was slight agreement between accelerometer-measured and parent-reported TPA (*κ*: 0.030) (*Table 3-2*). With the various demographic characteristics considered, there remained slight agreement between accelerometer-measured and parent-reported TPA, except among girls where there was disagreement between the two methods (*κ*: -0.012). Parent reports showed an overall sensitivity of 75.0% and specificity of 55.2% for meeting 180 minutes of TPA guideline per day. When stratified by the various demographic groups, parent reports showed sensitivity of 0.0%–100.0% and specificity of 49.6%–67.3% for meeting the TPA guideline.

Table 3-2: Spearman's correlation and classification accuracy between parent-reported and accelerometer-measured levels of TPA

	Spearman's correlation		Classification accuracy			
	Coefficient (*r*)	p-value	Agreement (%)	Sensitivity (%)	Specificity (%)	Kappa (*κ*)
All	0.140	0.009	56.0	75.0	55.5	0.030
Sex						
Boys	0.171	0.022	53.6	85.7	52.3	0.058
Girls	0.088	0.249	58.4	0.0	58.7	-0.012
Education class [a]						
High	0.233	0.002	57.9	66.7	57.6	0.035
Low	0.034	0.665	54.6	100.0	54.0	0.028
Residential area						
Urban	0.108	0.120	59.6	60.0	59.6	0.022
Rural	0.157	0.060	50.7	100.0	49.6	0.039
Country income level [b]						
HIC	0.112	0.233	67.2	66.7	67.3	0.050
MIC	0.156	0.016	50.4	80.0	49.8	0.024

Note: HIC = High-income countries; MICs = Middle-income countries.

[a] denotes 4 participants with missing data; [b] denotes derived variable based on World Bank classification. Agreement means the proportion of children who were accurately classified by both the parent reports and accelerometry (the criterion method) as meeting or not meeting the TPA

guidelines. Sensitivity means proportion of children who are accurately classified as meeting the TPA guidelines by parent reports. Sensitivity means proportion of children who are accurately classified as not meeting the TPA guidelines by parent reports. Kappa statistics by Landis and Koch[20]: <0.00 'poor agreement'; 0.00–0.20 'slight agreement'; 0.21–0.40 'fair agreement'; 0.41–0.60 'moderate agreement'; 0.61–0.80 'substantial agreement'; and 0.81–1.00 'almost perfect agreement'.

The Bland-Altman plots (*Figure 3-1*) demonstrated an over-estimation of habitual child TPA time from parent reports compared to the *activ*PAL™ measurement (mean bias: 69 min/day; SD: 126; 95% limits of agreement [LOA]: -179, 316). As shown in *Figure 3-1*, most parents with less active children over-reported their child's habitual TPA. There was also systematic bias in the measurement of child TPA by parent reports compared to accelerometer data, as parents tended to over-report their child's habitual TPA to a larger extent in less active children (*r*: -0.106; p=0.047).

The ROC analyses showed excellent classification accuracy for the De Craemer et al.[13] step-count cut-point with an AUC of 0.945 (95% CI: 0.928, 0.961), 100.0% sensitivity and 88.9% specificity (Supplementary Figure A available in *Appendix F-2* of this thesis). The Vale et al.[12] cut-point showed a fair classification accuracy (AUC: 0.773; 95% CI: 0.747, 0.799, Sensitivity: 100.0%; Specificity: 54.6%), and Gabel et al.[11] step-count cut-point showed a poor classification accuracy (AUC: 0.577; 95% CI: 0.557, 0.595; Sensitivity: 100.0%; Specificity: 15.1%).

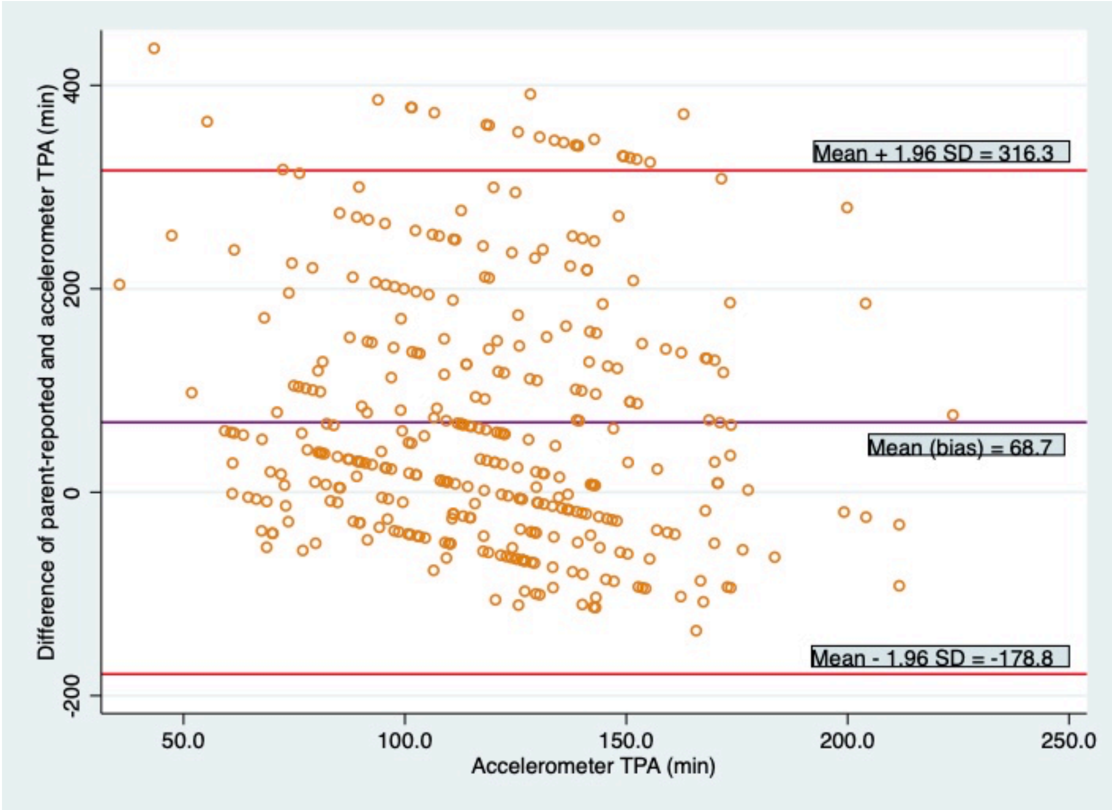

Figure 3-1: A 'modified' Bland-Altman Plot between accelerometer-measured and parent-reported child's habitual TPA. The figure shows mean bias (middle solid line) of 69 min/day in (over-) estimation of child's TPA by parent reports compared to accelerometer measurement and its associated lower and upper limits of agreement (below and above the mean bias line, respectively). The dots indicate that over-reporting of child's TPA by parent reports was higher among less active children.

Discussion

Our findings suggest that simple parent-reporting of child TPA is not likely to be adequate for global surveillance of the WHO physical activity guideline for pre-schoolers. However, we found that step-counting, using the De Craemer et al.[13] step-count threshold of 11,500 steps/day, provided an accurate way of assessing compliance with the guideline in this diverse group of pre-schoolers.

Only two studies have evaluated parent-reported TPA against accelerometry in young children.[6,7] Dwyer et al.[7] found very weak correlations ranging between 0.05 and 0.16 which were not statistically significant (p>0.05). Additionally, Dwyer et al.[7] reported mean biases of parent-reported TPA against accelerometry of 45 min/day (LOA: -104, 194) and 21 min/day (LOA: 122, 164) based on Sirard et al.[23] and Reilly et al.[24] accelerometry cut-points, respectively. Unlike our study, findings from Dwyer et al[7] were limited by a small sample size (n=67). Sarker et al.[6] found a weak correlation of 0.39 (95% CI: 0.19, 0.56) between parent-reported and accelerometer-measured child habitual TPA, which is higher than the correlation in our study (*r*: 0.14; p=0.009). Unlike Sarker et al.[6] which used Actical accelerometers, our study used *activ*PAL™ accelerometers which have been validated for measurement of TPA against direct observation in this age group.[10] Sarker et al.[6] had a mixed sample, involving infants, toddlers, pre-school and schoolchildren aged 4-70 months and did not report correlation/agreement specifically for each age group. The present study only included pre-schoolers aged 3-4 years that may have different activity patterns as well as spend less time with their parents compared to younger children in the Sarker et al.[6] study. Additionally, participants in both previous studies were from HICs[6,7]; whereas our study included participants from lower- and upper- middle-income countries and with diverse culture and lifestyles. Nevertheless, the results of the current study are consistent with a previous review of validation studies of physical activity measures in children, even though most validation studies included in the review involved children older than those participating in our study.[25] The poor/weak correlation in validation studies of parent-reported physical activity could be caused by parents over-reporting their child's physical activity due to social desirability[26] or because they do not know how much activity their child participate in during weekdays when they are at an ECEC centre for example.

Despite the importance of TPA in early childhood for current child health and development, and future health according to the WHO Ending Childhood Obesity (ECHO) Report[1] and WHO 2019 Guidelines,[2] there is currently no systematic global surveillance.[3] There is global surveillance of adherence to WHO physical activity guidelines in adolescents[27] and adults.[28] While proxy reports from parents are simple and cheap for monitoring physical activity in young children, our results suggest that they are not likely to be valid for global public health surveillance of physical activity in early childhood. Consequently, parent questionnaires may not be suitable for monitoring compliance with the WHO physical activity guidelines in early years. Given the need to for a globally validated physical activity measurement for surveillance purposes to monitor progress towards the global targets, and based on our results, step-counting may be a more accurate alternative to parent reports. At the moment, there is currently no consensus on culturally and geographically valid step-count targets for classifying 3 hours of TPA in pre-schoolers.[11–13] The present study suggests that a step-count threshold of at least 11,500 steps/day[13] be used for assessing compliance with meeting the TPA guideline in early years because it is geographically and culturally valid against TPA measured by the *activ*PAL™. There are barriers to using accelerometers in population-based studies as they are intrusive, require complicated data reduction and analysis, produce huge data sets, and are expensive,[5,9] at about a minimum of $254 USD per device up to > $1000 USD, depending on the device. As such, surveillance studies and national surveys in future could potentially use much simpler, cheaper devices like pedometers to assess the prevalence of compliance with WHO guidelines. Pedometers are highly correlated to accelerometer step-counts in young children[17,29] and adults[30]; however, exact step-count thresholds should be established as being accurate in the population they are being used before being included as surveillance measures due to potential differences between methods of measuring step-counts (including differences due to the placement of the device, e.g. with the *activ*PAL™ worn on the thigh and pedometers usually worn on the hip).

A strength of our study was the relatively large sample of young children compared to previous validation studies among this age group.[6–9] Moreover, to our knowledge, this is the first study to assess validity of parent reports of their children's physical activity based on a sample from vastly differing contexts, including lower- and upper-MICs as well as HICs. This is also the first study to cross-validate existing step-count thresholds in such a varied sample of pre-schoolers.

Our study had some limitations. Recruitment of participants in the SUNRISE study was determined independently in each country due to the varying contexts in which the study was conducted, including use of convenience cluster sampling.[4] The sample was not representative. However, for a methodological study the main requirements are adequate sample size, wide range of settings, and a range of levels of TPA from low to high, and all these requirements were met in our study. We did not have any low-income countries (LIC) study participants as classified by the World Bank. However, our study included participants from Bangladesh which is classified as a LIC according to the Organisation for Economic Co-operation and Development's (OECD) Development Assistant Committee (DAC; https://www.oecd.org/dac/financing-sustainable-development/development-finance-standards/daclist.htm) and also included three lower-MICs. The parent-reported questions in our study were based on available physical activity, sedentary behaviour, and sleep guidelines for the early years,[16] and alternative questions might have higher validity. In addition, it is possible that the observed bias in over-reporting of child's TPA by parents varied between countries due to cultural differences; however, with our sample size we were not adequately powered to explore differences in biases by country of origin. As such, a further study focusing on potential differences in the biases in physical activity reporting by parents across countries may be useful. We identified a gender difference in accuracy of parent reporting of TPA (more accurate in the boys than girls) – the reasons for this are not clear and may be worth investigating further in future. However, correlations between parent-reported TPA and accelerometer-measured TPA, though statistically significant, were very low in the boys in the present study and so the practical significance of this gender difference is probably quite limited – validity of parent reporting was low in both boys and girls. Further, we used research-grade accelerometer to test the three existing step-count thresholds and therefore cheaper pedometers need to be validated before use. Lastly, there was a suggestion of a possible gender difference in the classification accuracy as there was disagreement between the two methods in measurement of habitual TPA among girls which also requires further research.

Conclusions

Despite the importance of TPA in early childhood for current child health and development, and future health according to the WHO ECHO Report[1] and WHO 2019 Guidelines,[2] there is currently no global surveillance of TPA in early childhood, and one major barrier to a surveillance system is cost and complexity of the measurement method. The present study provides evidence that parent reports may have limited validity for this purpose as parents cannot recall their child's physical activity adequately, at least not using fairly simple questions. However, our study also shows that step-counts may be an accurate and relatively simple, potentially low-cost, alternative to assessment of progress towards meeting the global physical activity targets in this age group.

Practical implications

- Parent reports of their child's level of physical activity are not accurate.
- An alternative simple objective monitoring method is required, especially for low-and-middle--income countries.
- Step-counting (e.g., using pedometers) provides an accurate low-cost option and may be suitable internationally for population monitoring of physical activity in early childhood to improve children's health and prevent obesity and related diseases, such as diabetes, high blood pressure and some cancers.

Author contributions:

TM-V, XJ, and JJR contributed to the conceptualisation, data analysis and interpretation, drafting, review, and final approval of the manuscript. ADO, MST, CED, AAF, CT, DK, GH, HKT, KHC, ML, MSH, PC, and PWPC contributed to data acquisition as well as reviewed and approved the manuscript.

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Confirmation of ethical compliance

The SUNRISE study protocol was reviewed and approved by Human Research Ethics Committee at the UOW (2018/044) and ethics committees in each participating country; all parents of participating children gave informed consent.

Declarations of interest

None

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Published article references

1. World Health Organization. *Report of the Commission on Ending Childhood Obesity*.; 2016.

2. World Health Organization. *World Health Organisation Guidelines for Physical Activity, Sedentary Behaviour, and Sleep for Children under 5 Years of Age*.; 2019.

3. Aubert S, Brazo-Sayavera J, González SA, et al. Global prevalence of physical activity for children and adolescents; inconsistencies, research gaps, and recommendations: a narrative review. *Int J Behav Nutr Phys Act*. 2021;18(1):1-11. doi:10.1186/s12966-021-01155-2

4. Okely AD, Reilly JJ, Tremblay MS, et al. Cross-sectional examination of 24-hour movement behaviours among 3- and 4-year-old children in urban and rural settings in low-income, middle-income and high-income countries: the SUNRISE study protocol. *BMJ Open*. 2021;11(10):e049267. doi:10.1136/bmjopen-2021-049267

5. Hidding LM, Chinapaw MJM, Poppel MNM Van, Mokkink LB. An Updated Systematic Review of Childhood Physical Activity Questionnaires. *Sport Med*. 2018;48(12):2797-2842. doi:10.1007/s40279-018-0987-0

6. Sarker H, Anderson LN, Borkhoff CM, et al. Validation of parent-reported physical activity and sedentary time by accelerometry in young children. *BMC Res Notes*. 2015;8:735. doi:10.1186/s13104-015-1648-0

7. Dwyer GM, Hardy LL, Peat JK, Baur LA. The validity and reliability of a home environment preschool-age physical activity questionnaire (Pre-PAQ). *Int J Behav Nutr Phys Act*. 2011;8(86):1-13. doi:https://doi.org/10.1186/1479-5868-8-86

8. Bacardi-Gascón M, Reveles-Rojas C, Woodward-lopez G, Crawford P, Jiménez-cruz A. Assessing the Validity of a Physical Activity Questionnaire Developed for Parents of Preschool Children in Mexico. *J Heal Popul Nutr*. 2012;30(4):439-446. doi:10.3329/jhpn.v30i4.13327

9. Bingham DD, Collings PJ, Clemes SA, et al. Reliability and Validity of the Early Years Physical Activity Questionnaire (EY-PAQ). *Sports*. 2016;4(2):1-14. doi:10.3390/sports4020030

10. Davies G, Reilly JJ, Mcgowan AMYJ, Dall PM, Granat MH, Paton JY. Validity, Practical Utility, and Reliability of the activPAL in Preschool Children. *Med Sci Sport Exerc*. 2012;44(4):761-768. doi:10.1249/MSS.0b013e31823b1dc7

11. Gabel L, Proudfoot NA, Obeid J, et al. Step count targets corresponding to new physical

activity guidelines for the early years. *Med Sci Sports Exerc*. 2013;45(2):314-318. doi:10.1249/MSS.0b013e318271765a

12. Vale S, Trost SG, Duncan MJ, Mota J. Step based physical activity guidelines for preschool-aged children. *Prev Med (Baltim)*. 2015;70(January):78-82. doi:10.1016/j.ypmed.2014.11.008.Copyright

13. De Craemer M, De Decker E, De Bourdeaudhuij I, Verloigne M, Manios Y, Cardon G. The translation of preschoolers' physical activity guidelines into a daily step count target. *J Sports Sci*. 2015;33(10):1051-1057. doi:10.1080/02640414.2014.981850

14. Cliff DP, Reilly JJ, Okely AD. Methodological considerations in using accelerometers to assess habitual physical activity in children aged 0-5 years. *J Sci Med Sport*. 2009;12(5):557-567. doi:10.1016/j.jsams.2008.10.008

15. De Decker E, De Craemer M, Santos-Lozano A, Van Cauwenberghe E, De Bourdeaudhuij I, Cardon G. Validity of the ActivPAL™ and the ActiGraph monitors in preschoolers. *Med Sci Sports Exerc*. 2013;45(10):2002-2011. doi:10.1249/MSS.0b013e318292c575

16. Okely AD, Ghersi D, Hesketh KD, et al. A collaborative approach to adopting/ adapting guidelines - The Australian 24-Hour Movement Guidelines for the early years (Birth to 5 years): an integration of physical activity, sedentary behavior, and sleep. *BMC Public Health*. 2017;17(Suppl 5):896. doi:10.1186/s12889-017-4867-6

17. Aminian S, Hinckson EA. Examining the validity of the ActivPAL monitor in measuring posture and ambulatory movement in children. *Int J Behav Nutr Phys Act*. 2012;9:1-9. doi:10.1186/1479-5868-9-119

18. World Health Organization. The STEPS Instrument. *The STEPS Instruments*. Accessed October 19, 2019. https://www.who.int/ncds/surveillance/steps/instrument/en/

19. Fowler J, Cohen L, Jarvis P. *Practical Statistics for Field Biology*. 2nd ed. John Wiley & Sons Ltd; 2009.

20. Landis JR, Koch GG. The Measurement of Observer Agreement for Categorical Data. *Biometrics*. 1977;33(1):159. doi:10.2307/2529310

21. Krouwer JS. Why Bland-Altman plots should use X, not (Y + X)/2 when X is a reference method. *Stat Med*. 2008;27(5):778-780. doi:10.1002/sim.3086

22. Mehdi T, Ahmadi BN. Kernel Smoothing For ROC Curve And Estimation For Thyroid Stimulating Hormone. *Int J Public Heal Res Spec Issue*. Published online 2011:239-242.

23. Sirard JR, Trost SG, Pfeiffer KA, Dowda M, Pate RR. Calibration and evaluation of an

objective measure of physical activity in preschool children. *J Phys Act Heal*. 2005;2(3):345-357. doi:10.1123/jpah.2.3.345

24. Reilly JJ, Coyle J, Kelly L, et al. An Objective Method for Measurement of Sedentary Behavior in 3- to 4-Year Olds. *Obes Res*. 2003;11(10):8-11. doi:10.1038/oby.2003.158

25. Adamo KB, Prince SA, Tricco AC, Connor-Gorber S, Tremblay M. A comparison of indirect versus direct measures for assessing physical activity in the pediatric population: A systematic review. *Int J Pediatr Obes*. 2009;4(1):2-27. doi:10.1080/17477160802315010

26. Shephard RJ. Limits to the measurement of habitual physical activity by questionnaires. *Br J Sports Med*. 2003;37:197-206. doi:10.1136/bjsm.37.3.197

27. Guthold R, Stevens GA, Riley LM, Bull FC. Global trends in insufficient physical activity among adolescents: a pooled analysis of 298 population-based surveys with 1·6 million participants. *Lancet Child Adolesc Heal*. 2020;4(1):23-35. doi:10.1016/S2352-4642(19)30323-2

28. Bonita R, de Courten M, Dwyer T, Jamrozik K, Winkelmann R. Surveillance of risk factors for noncommunicable diseases: The WHO STEPwise approach. Summary. Published online 2001.

29. De Craemer M, De Decker E, Santos-Lozano A, et al. Validity of the Omron pedometer and the actigraph step count function in preschoolers. *J Sci Med Sport*. 2015;18(3):289-293. doi:10.1016/j.jsams.2014.06.001

30. Behrens TK, Dinger MK. Comparisons of accelerometer and pedometer determined steps in free living samples. *J Phys Act Heal*. 2011;8(3):390-397. doi:10.1123/jpah.8.3.390

3.4 Preface references

1. Okely AD, Reilly JJ, Tremblay MS, et al. Cross-sectional examination of 24-hour movement behaviours among 3- and 4-year-old children in urban and rural settings in low-income, middle-income and high-income countries: the SUNRISE study protocol. *BMJ Open*. 2021;11(10):e049267. doi:10.1136/bmjopen-2021-049267

2. Sallis JF, Owen N, Fotheringham MJ. Behavioral epidemiology: A systematic framework to classify phases of research on health promotion and disease prevention. *Annals of Behavioral Medicine*. 2000;22(4):294-298. doi:10.1007/BF02895665

3. Reilly JJ, Aubert S, Brazo-Sayavera J, Liu Y, Cagas JY, Tremblay MS. Surveillance to improve physical activity of children and adolescents. *Bull World Health Organ*. 2022;100(12):815-824. doi:10.2471/BLT.22.288569

4. Ding D, Chastin S, Salvo D, et al. Realigning the physical activity research agenda for population health, equity, and wellbeing. *The Lancet*. 2024;6736(24):4-6. doi:10.1016/S0140-6736(24)01540-X

5. Kang H. The prevention and handling of the missing data. *Korean J Anesthesiol.* 2013;64(5):402-406. doi:10.4097/kjae.2013.64.5.402

6 Austin PC, White IR, Lee DS, van Buuren S. Missing Data in Clinical Research: A Tutorial on Multiple Imputation. *Canadian Journal of Cardiology*. 2021;37(9):1322-1331. doi:10.1016/j.cjca.2020.11.010

7. Gabel L, Proudfoot NA, Obeid J, et al. Step count targets corresponding to new physical activity guidelines for the early years. *Med Sci Sports Exerc*. 2013;45(2):314-318. doi:10.1249/MSS.0b013e318271765a

8. Vale S, Trost SG, Duncan MJ, Mota J. Step based physical activity guidelines for preschool-aged children. *Prev Med (Baltim)*. 2015;70:78-82. doi:10.1016/j.ypmed.2014.11.008

9. De Craemer M, De Decker E, De Bourdeaudhuij I, Verloigne M, Manios Y, Cardon G. The translation of preschoolers' physical activity guidelines into a daily step count target. *J Sports Sci*. 2015;33(10):1051-1057. doi:10.1080/02640414.2014.981850

10. Tremblay MS. Challenges in global surveillance of physical activity. *Lancet Child Adolesc Health*. 2020;4(1):2-3. doi:10.1016/S2352-4642(19)30348-7

11. Oliver M, Schofield GM, Kolt GS. Physical Activity in Preschoolers: Understanding Prevalence and Measurement Issues. *Sports Medicine*. 2007;37(12):1045-1070. doi:10.2165/00007256-200737120-00004

12. Adamo KB, Prince SA, Tricco AC, Connor-Gorber S, Tremblay M. A comparison of indirect versus direct measures for assessing physical activity in the pediatric population: A systematic review. *International Journal of Pediatric Obesity*. 2009;4(1):2-27. doi:10.1080/17477160802315010

13. Hidding LM, Chinapaw MJM, Poppel MNM Van, Mokkink LB. An Updated Systematic Review of Childhood Physical Activity Questionnaires. *Sports Medicine*. 2018;48(12):2797-2842. doi:10.1007/s40279-018-0987-0

14. Bingham DD, Collings PJ, Clemes SA, et al. Reliability and Validity of the Early Years Physical Activity Questionnaire (EY-PAQ). *Sports*. 2016;4(2):1-14. doi:10.3390/sports4020030

15 Sallis JF, Owen N, Fotheringham MJ. Behavioral epidemiology: A systematic framework to classify phases of research on health promotion and disease prevention. Annals of Behavioral Medicine [Internet]. 2000;22(4):294–8. Available from: https://academic.oup.com/abm/article/22/4/294/4633687

Chapter 4: Prevalence and correlates of adherence to the global total physical activity guideline based on step counting among 3- to 4-year-olds: Evidence from SUNRISE Pilot Studies from 17 countries

4.1 Preface

This chapter presents evidence on the prevalence and correlates of meeting the global TPA guideline based on the step count threshold of 180 minutes per day. Knowledge from the validation study from Chapter 3 significantly influenced the present chapter. This chapter includes an article "Prevalence and correlates of adherence to the global total physical activity guideline based on step counting among 3- to 4-year-olds: Evidence from SUNRISE Pilot Studies from 17 countries" that was published in the *Journal of Physical Activity and Health.*

4.1.1 Chapter introduction and rationale

Based on findings from the validation study (Chapter 3), daily step count with a threshold of 11,500 steps[1] provided an accurate measure for assessing the global TPA guideline in young children from varied backgrounds globally, including LMICs in the SSA settings. As previously noted, validating measurement methods is an important step in developing evidence-based policy interventions to improve population's health in line with the Behavioural Epidemiology Framework.[2,3] This is also essential for developing culturally responsive and tailored public health interventions.[4] Building on the validated step count threshold (Chapter 3), this chapter addresses an important gap in the literature by addressing the lack of evidence on the prevalence and correlates of meeting the global guidelines in young children from low- and middle-income SSA contexts[5–8] since the publication of the guidelines for over five years ago.[9]

Although valid measurement methods (e.g., accelerometry-based physical activity duration) have been used in the recently published studies from SSA contexts,[10,11] these methods may not be feasible in global surveillance studies due to their costs and complexity.[3,12–15] As such, evidence generated using feasible and culturally appropriate methods is needed to inform sustainable surveillance systems and tailored policy interventions to improve the population health,[16] as well as to promote equity in movement behaviour research globally.[17]

To address this research gap, this chapter provides evidence on the prevalence and correlates of meeting the global TPA guideline among young children from low- and middle-income SSA contexts using the validated daily step count threshold of 11,500 steps.[1] As previously stated, this was a secondary analysis of data from two pilot phases of the SUNRISE International Study.[18] The preface section of Chapter 3 above provides a description of the two pilot study phases, which expands on the methods used in the published article presented later in this chapter.

4.1.2 Data management and analysis methods

As noted above, data used for the secondary analysis presented in this chapter were obtained from the University of Wollongong in Excel format. The data file comprised two Excel sheets: dataset and data dictionary. The data dictionary sheet contained description of the variable name and explanation as appropriate. The data dictionary was used to identify the variables relevant to the analyses presented in this chapter. The dataset sheet contained records for 955 children who wore *activ*PAL^{TM} for physical activity measurement during the pilot phases 1 and 2 of the SUNRISE International Study. The data also included sociodemographic information obtained from parents of participating children and children's anthropometric measurements (height and weight).

Raw data were imported into Stata/IC v.16.1 for Mac (StataCorp, College Station, Texas, USA), a statistical software package that was used for conducting all data cleaning and analyses. Similar to procedure described in Chapter 3, cleaning of data presented in this chapter involved converting string variables to numerical variables (e.g., sex was recorded as boy or girl and converted to numerical values 1 and 2, respectively), re-coding variables (e.g., age was recorded as continuous variable and was recoded into two categories [3- and 4-year olds] which were used for analysis), and creating a new variable (e.g., for country income group, including low-, middle-, and high-income countries). All data were checked for missing values and a 'complete case analysis' method was used for handing missing data during data analysis (see *Section 5.1.2.7* of Chapter 5 for details on handling missing data).[19,20]

Data analysis methods used in this chapter included both descriptive and inferential statistical analyses. A detailed description of these methods is provided in the published article presented later in this chapter (*Section 3.3*). In summary, descriptive analyses were performed to describe characteristics of participants, and summary statistics were presented as means and standard deviations for continuous variables that were normally distributed, and frequencies and percentages for categorical variables. The associations between dependent and independent variables were assessed using logistics regression modelling. As appropriate, results for inferential statistical were presented with associated p-values and 95% confidence intervals. Statistical significance was determined at 5% level (i.e., $p<0.05$) in the multivariable analyses.

4.2 Chapter significance and contribution to research

This chapter represents an important application of the validated step count threshold established in Chapter 3, advancing our understanding of physical activity patterns among 3–4 year olds globally, including in LMICs. The chapter highlights the importance of using a simple, validated measurement method that is practical and culturally appropriate for global surveillance, addressing a key gap in monitoring physical activity in young children worldwide.[21,22]

Importantly, this chapter further reveals a critical gap in the literature on the absence of evidence from low-income countries, particularly in SSA, which forms the rationale for Chapter 5. While Chapter 4 successfully captures data from middle- and high-income countries, the lack of representation from low-income SSA contexts highlights the need for evidence on compliance with the global 24-hour movement behaviour guidelines generated using feasible measurement approaches. This evidence is presented in the following chapter (Chapter 5).

4.3 Published article

As previously mentioned, this article was published as original research in the *Journal of Physical Activity and Health* in June 2024. The final, proof-corrected Microsoft Word version of published article is presented in the following section of this chapter for readability and the PDF version of published format is available in *Appendix G-1* of this thesis.

Suggested citation

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Author contributions

I am the primary (first) author of this article. In consultation with and inputs from my supervisors (JJR and XJ), I conceived and designed this study. XJ obtained data from the SUNRISE Coordinating Centre based at the University of Wollongong. I cleaned and analysed the data, drafted the first version of the manuscript and revised it based on inputs from all authors, submitted the final version of the manuscript for publication, and addressed reviewer comments in consultation with my supervisors. All authors approved the final version before submission in line with the International Committee of Medical Journal Editors authorship guidelines (https://www.icmje.org/recommendations/browse/roles-and-responsibilities/defining-the-role-of-authors-and-contributors.html).

Supplementary materials

Supplementary material mentioned in this article is presented in *Appendix G-2* of this thesis.

Title: Prevalence and correlates of adherence to the global total physical activity guideline based on step counting among 3- to 4-year-olds: Evidence from SUNRISE Pilot studies from 17 countries

Author names:

Tawonga W. Mwase-Vuma[1,2], Xanne Janssen[1], Kar Hau Chong[3], Anthony D. Okely[3], Mark S. Tremblay[4], Catherine E. Draper[5], E. Kipling Webster[6], Alex Antonio Florindo[7], Amanda E. Staiano[8], Bang Nguyen Pham[9], Chiaki Tanaka[10], Denise Koh[11], Guan Hongyan[12], Hong K. Tang[13], Marie Löf[14], Mohammad Sorowar Hossain[15], Nyaradzai E. Munambah[16,17], Penny Cross[3], PW Prasad Chathurangana[18], John J. Reilly[1]

Affiliations:

1. Department of Psychological Sciences and Health, University of Strathclyde, Glasgow, Scotland
2. Centre for Social Research, University of Malawi, Zomba, Malawi
3. School of Health and Society, Faculty of the Arts, Social Sciences and Humanities, University of Wollongong, New South Wales, Australia
4. Children's Hospital of Eastern Ontario Research Institute, Ottawa, Canada
5. SAMRC/Wits Developmental Pathways for Health Research Unit, University of the Witwatersrand, Johannesburg, South Africa
6. Department of Kinesiology, Recreation, and Sport Studies, University of Tennessee, Knoxville, USA
7. School of Arts, Sciences, and Humanities, University of Sao Paulo, Brazil
8. Pennington Biomedical Research, Louisiana State University, Baton Rouge, USA
9. Papua New Guinea Institute of Medical Research, Goroka, Papua New Guinea
10. Tokyo Kasei Gakuin University, Tokyo, Japan
11. Centre of Community Education & Well-being, Faculty of Education, Universiti Kebangsaan Malaysia, Bangi, Malaysia
12. Capital Institute of Pediatrics, Beijing, China
13. Pham Ngoc Thach University of Medicine, Ho Chi Minh City, Vietnam
14. Department of Biosciences and Nutrition, Karolinska Institutet, Stockholm, Sweden
15. Biomedical Research Foundation, Dhaka, Bangladesh
16. Rehabilitation Sciences Unit, Faculty of Medicine and Health Sciences, University of Zimbabwe, Harare, Zimbabwe
17. Department of Occupational Therapy and Physiotherapy, School of Allied Health Sciences, University of Namibia, Windhoek, Namibia

18. Department of Paediatrics, Faculty of Medicine, University of Colombo, Colombo, Sri Lanka

Corresponding author:

Tawonga W. Mwase-Vuma
Department of Psychological Sciences and Health
University of Strathclyde, Graham Hills Building (Room 535) 50 George Street
Glasgow G1 1QE, Scotland
Email: tawonga.mwase-vuma@strath.ac.uk
ORCID: 0000-0002-0189-1488
Twitter: @taomwase

Abstract

Background

There is limited evidence from globally diverse samples on the prevalence and correlates of meeting the global guideline of 180 minutes/day of total physical activity (TPA) among 3-4-year-olds.

Methods

Cross-sectional study involving 797 (49.2% girls) 3-4-year-olds from 17 middle- and high-income countries who participated in the pilot phases 1 and 2 of the SUNRISE Study. Daily step-count was measured using thigh-worn *activ*PAL^{TM} accelerometers. Children wore the accelerometers for at least one 24-hour period. Children were categorized as meeting the TPA guideline based on achieving ≥11,500 steps/day. Descriptive analyses were conducted to describe the proportion of meeting the TPA guideline for the overall sample and each of the sociodemographic variables and 95% confidence intervals (CI) were calculated. Multivariable logistic regression was used to determine the sociodemographic correlates of meeting the TPA guideline.

Results

Mean daily step-count was 10,295 steps/day (SD=4084). Approximately one-third of the sample (30.9%, 95% CI=27.6–34.2) met the TPA guideline. The proportion meeting the guideline was significantly lower among girls (adjusted OR [aOR]=0.70, 95% CI=0.51–0.96) and 4-year-olds (aOR=0.50, 95% CI=0.34–0.75) and higher among rural residents (aOR=1.78, 95% CI=1.27–2.49) and those from lower-middle-income countries (aOR=1.35, 95% CI=0.89–2.04).

Conclusions

A minority of children in this global sample met the TPA guideline, and the risk of not meeting the guideline differed by sociodemographic indicators. These findings suggest the need for more surveillance of TPA in young children globally, and possibly interventions to improve childhood health and development.

Key words: Child; preschool; accelerometry; physical activity surveillance; cross-sectional studies

Introduction

The World Health Organization (WHO) guidelines on physical activity for children under the age of 5 years recommend that children aged 3-4 years should accumulate a minimum of 180 minutes/day of total physical activity (TPA), including a minimum of 60 minutes/day of moderate- to vigorous-intensity physical activity (MVPA), for healthy growth and development.[1] Physical activity has several benefits in childhood and across the lifespan.[2] For example, physical activity is associated with improved motor development, adiposity, cardiometabolic and psychosocial health as well as bone and skeletal health.[3,4] Thus, promoting physical activity is critical for optimal health and wellbeing of young children, and is one of the key components for tackling the obesity pandemic worldwide.[1] Despite the publication of these guidelines in 2019, there is limited evidence from globally diverse samples on adherence to the WHO TPA guideline among 3 and 4 year-old children. Moreover, evidence on adherence to the WHO TPA guideline is predominantly from studies conducted in high-income countries (HICs).[5] Based on the Behavioural Epidemiology Framework,[6] which lays out five systematic phases of research studies on health-related behaviours in order to enhance the population's health, large, cross-country and intercontinental descriptive studies are required to understand geographical and cultural variations in adherence to the WHO TPA guideline. Such studies will ultimately inform the need for surveillance and evidence-based interventions and practices to improve children's health. One possible reason for the lack of global evidence, including in low- and middle-income countries (LMICs), could be the high costs for surveillance and lack of cross-cultural validity and appropriateness of the measurement methods.[5]

Common methods to measure guideline adherence in large-scale studies include proxy-reports from parents and device-based measures (e.g., accelerometry and pedometers). Recent evidence suggests that parents may not accurately report the time their 3-4 year-old child spends in physical activity.[7] Mwase-Vuma et al.[7] found that parents tended to substantially over-estimate the time their child spent in physical activity compared to device-based measurements. Consequently, step-counting (using devices like pedometers which are less expensive than accelerometers) has been suggested as a low-cost alternative for global surveillance of physical activity in early childhood[7] to enhance public health surveillance globally.[8]

Previous studies have proposed varying step-count thresholds derived from ActiGraph accelerometer output as equivalent to 180 minutes/day of TPA in pre-school-aged children.[9–11] Step-based goals have practical utility as they are relatively accurate, intuitive, motivating, and easily measured and understood by the public.[12] Our recent study[7] used steps derived from *activ*PAL™ to cross-validate three existing step-count thresholds.[9–11] We found that the step-counting threshold of 11,500 steps/day proposed by De Craemer et al.[11] provided excellent classification for meeting the WHO TPA guideline as measured by accelerometry,[7] and is therefore appropriate for the global surveillance of the WHO TPA guideline in early childhood.

Few published studies have assessed adherence to the TPA guideline using the 11,500 steps/day threshold in pre-schoolers aged 3-4 years.[13–16] These studies focused on high-income countries (HIC) in Europe and Asia, which may limit their generalisability in other contexts.[13–16] We used the De Craemer et al.[11] threshold of 11,500 steps/day as measured by *activ*PAL™ to understand how step-counting can effectively inform the WHO TPA guideline for 3-4 year olds globally.

Methods

Study design and participants

This was a cross-sectional study using *activ*PAL™ (PAL Technologies Ltd, Glasgow, Scotland) data collected during phases 1 and 2 (collectively considered the Pilot Phase) of the SUNRISE International Study of Movement Behaviours in the Early Years (https://sunrise-study.com/). Methods of recruitment and data collection have been described previously.[7,17] In short, data collection for the first two pilot study phases were conducted between March 2018 and September 2020 and involved over 2500 children aged 2-6 years from 23 countries. Participating countries were initially recruited by members of the SUNRISE Leadership Group through their existing collaborations, and subsequently through invitation or expression of interest.[17] Of the 23 participating countries, only 17 countries used an *activ*PAL™ accelerometer and data collection in these countries was completed by November 2019, before the COVID-19 pandemic. These 17 countries were included in the current study.

Participants were recruited using convenience cluster sampling from Early Childhood Education and Care (ECEC) centres, schools, community centres, or at village level (hereafter "study site").[17] A consent was required from the ECEC centre or school director prior to seeking consent from parents. The process was slightly different for countries where recruitment was done through the community or at village level. The parents of eligible children were then contacted to provide written informed consent for their child's participation. Children were eligible to participate in the Pilot Phase of the SUNRISE Study if they were aged 3 and 4 years, their parents consented for their participation, and were able to wear an accelerometer. However, other participating countries recruited older children due to the vastly differing context and pre-school age. Consequently, the main inclusion criteria for the current study were having *activ*PAL™ data and participant age.

Data for *activ*PAL™ was available for 955 children from 17 diverse countries who participated in the Pilot Phase of the SUNRISE Study. Of these, 158 were excluded because they were aged below 3 years or 5 years and older. Hence, the analytical sample comprised 797 pre-schoolers aged 3.0 to < 5.0 years. We will not present data for the excluded children who did meet the age criteria for the present study. The Human Research Ethics Committee at the University of Wollongong (2018/044) and ethics committees in each participating country approved all procedures in the SUNRISE Study.

Measurement of step-count

Step-counts were assessed using thigh-worn *activ*PAL™ accelerometers. The *activ*PAL™ records time spent sitting/lying, standing, and stepping in 15-seconds epochs,[18] and has been validated for measurement of step-counting in pre-schoolers[19] and older children aged 9-10 years.[20] The *activ*PAL™ monitors were waterproofed using a piece of Tegaderm transparent dressing. During a visit to the study site, trained research staff used another dressing to place the monitor on the child's right anterior thigh, midway between the hip and knee in the midline. Children were asked to continuously wear the monitors for 3-5 days as described previously.[7,17] Parents of participating children were sent a letter with instructions to ensure the monitors were worn properly, and additional tape was provided to re-attach the monitor in case it became loose on the child's thigh. The centre staff or teachers also helped to ensure that children recruited through ECEC centres, schools, or community centres wore the monitors properly throughout school days. On the last day of data collection, the research staff removed the monitors from participating children at the study site. In some countries (e.g., Japan), parents removed the monitors on the morning of the last day and sent them to the study site, where the research staff collected them. To be included in the current study, a child was required to have at least 1 valid day accelerometry data[21] (i.e., data for at least one 24-hour period on either a weekday or weekend). The average daily step-count was calculated and classified as meeting or not meeting the 180 minutes/day of TPA based on the threshold of 11,500 steps/day.[7]

Potential correlates of time spent in physical activity

There were five potential correlates, and these were explored based on what was available from the SUNRISE Study protocol,[17] and identified from previous studies.[22] Potential correlates examined in this study included the child's sex and age, residential area (urban/rural), parental/caregiver education level, and country-income level. As described previously,[7,17] the SUNRISE Study used a modified version of the WHO STEPS survey questionnaire[23] to collect sociodemographic data from participants. The questionnaire was completed by parent/ legal guardian self-administration, or as an interview with data collectors, for example, where literacy posed challenges.[17] The child's date of birth (or age in complete years if the child's date of birth was not known) was reported by parents and this was used to determine the child's age in months and years. This was also used to group participants into two categories based on their age: 3.0 to <4.0 and 4.0 to <5.0 years. The child's sex was recorded as either boy or girl. In addition, parents reported the highest education a member of their household completed based on their country's educational classification and this was dichotomized as low (secondary/high school or below) or high (tertiary education or above) education. This was used as a proxy for family socioeconomic status.[24] The child's residential area was recorded as urban or rural based on the location of the study site where they were recruited. Participating country's income level was defined as lower-middle (L-MIC), upper-middle (U-MIC), or high-income country (HIC) using the World Bank classification.[25]

Statistical analysis

Descriptive analyses were conducted to characterise the sample, and were presented as mean and standard deviation (SD) for continuous data if normally distributed or frequency and percentage (%) for categorical data. Descriptive analyses were also conducted to describe the proportion of children meeting the TPA guideline based on the 11,500 steps/day threshold for the overall sample and each of the sociodemographic variables and 95% confidence intervals (CI) were calculated. The association between potential correlates and adherence to the TPA guideline based on the 11,500 steps/day threshold was modelled using logistic regression. First, univariable analysis was performed to determine the association between meeting the guideline and each of the potential correlates (age, sex, parent education, residential area, and country income level). Potential correlates were retained for use in the multivariable analysis if they were at least marginally significant ($p<0.10$).[26]

Multivariable logistic regression analyses were conducted to identify correlates of meeting the TPA guideline based on the 11,500 step/day threshold. Potential correlates that were identified in the univariable analyses ($p<0.10$) were introduced into the multivariable model all at once using the stepwise backward selection method.[27] The final model included all variables determined as correlates of meeting the guideline using Wald's p-value at 5% significance level. All analyses were conducted in Stata/IC v.16.1 for Mac (StataCorp, College Station, Texas, USA).

Results

Of the 955 children with valid *activ*PAL™ data evaluated in the present study, 797 were aged 3.0 to <5.0 years (mean age 4.0 [SD 0.3] years). Participants were from 17 countries: 5 L-MICs, 5 U-MICs, and 7 HICs (*Table 4-1*). *Table 4-2* reports the descriptive characteristics of participants included in the present study. The proportion of boys and girls included in our study was similar. Most children were aged 4.0 to <5.0 years. A slight majority (52.6%) lived in urban areas and nearly two-thirds (62.4%) were from L-MICs or U-MICs. Overall, children achieved an average of 10,295 (SD = 4084) steps/day as measured by the *activ*PAL™.

Table 4-1: Proportion of participants included in the present study by country and country's income level

Country	Frequency	Percent
High-income countries		
Australia	22	7.3
Canada	29	9.7
Hong Kong	77	25.7
Japan	59	19.7
South Korea	32	10.7
Sweden	76	25.3
USA	5	1.7
Total	300	100.0
Upper-middle income countries		
Brazil	47	15.2
China	103	33.3
Malaysia	69	22.3
South Africa	63	20.4
Sri Lanka	27	8.7
Total	309	100.0
Lower-middle income countries		
Bangladesh	27	14.4
Indonesia	60	31.9
Papua New Guinea	70	37.2
Vietnam	17	9.0
Zimbabwe	14	7.5
Total	188	100.0

Table 4-2: Sociodemographic characteristics of participants, presented as frequencies and percentages unless otherwise specified, along with their mean daily step counts

Characteristics	Frequency	Percent	Mean total step-count (SD), steps/day		
			Weekday N = 750	Weekend N = 214	Overall N = 797
All	797	100.0	10,241 (4201)	10,279 (3943)	10,295 (4084)
Sex					
Boys	405	50.8	10,460 (4458)	10,562 (4112)	10,490 (4275)
Girls	392	49.2	10,009 (3902)	10,047 (3802)	10,093 (3872)
Age group, years					
3.0 to <4.0	133	16.7	11,751 (4318)	10,807 (3552)	11,764 (4290)
4.0 to <5.0	664	83.3	9936 (4114)	10,178 (4014)	10,000 (3980)
Education class [a]					
High	426	54.8	9682 (3710)	10,161 (3525)	9738 (3621)
Low	352	45.2	10,774 (4604)	10,413 (4309)	10,831 (4441)
Residential area					
Urban	419	52.6	9767 (3961)	9818 (4087)	9709 (3775)
Rural	378	47.4	10,798 (4409)	10,659 (3795)	10,945 (4314)
Country income level					
HIC	300	37.6	10,274 (3359)	9432 (3500)	10,223 (3299)
Upper-MIC	309	38.8	9173 (3059)	10,212 (3716)	9369 (3046)
Lower-MIC	188	23.6	11,872 (6040)	15,504 (4453)	11,931 (5848)

Notes: *a* denotes participants with missing information on education class (n=19); SD, standard deviation; HIC, high-income countries; MIC, middle-income countries; Low education class means secondary/high school or below; High education class means tertiary education or above

Figure 4-1 (and Supplementary Table 1 available in *Appendix G-2* of this thesis) shows the proportion of participants meeting the TPA guideline. Almost a third (30.9%, 95% CI = 27.6–34.2) of the pre-schoolers met the TPA guideline. The proportion meeting the TPA guideline was significantly higher among boys, 3-year-olds, rural residents, and those from L-MICs.

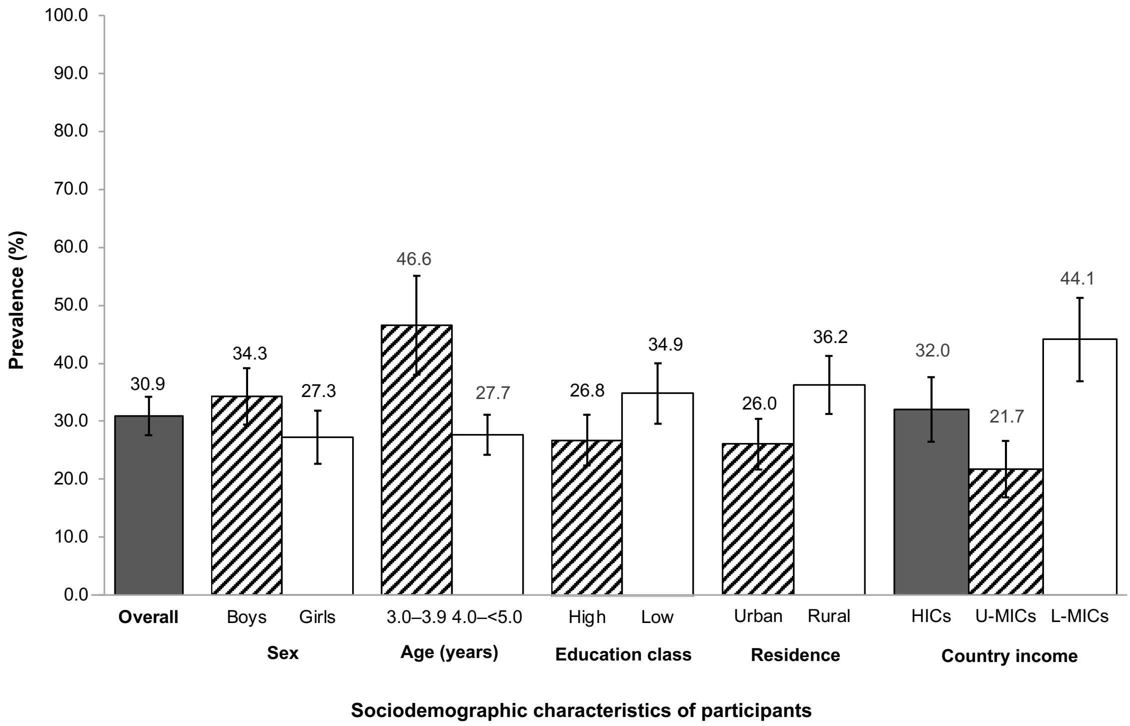

Figure 4-1: Prevalence of meeting the WHO TPA guideline based on step-count threshold of at least 11,500 steps/day by participant sociodemographic characteristics. The prevalence rate is presented for the overall sample and each of the sociodemographic characteristics of participants. Each bar represents the estimated prevalence of meeting the guideline, and the vertical lines extending from each bar indicate the corresponding 95% confidence intervals. Low education class means secondary/high school or below; High education class means tertiary education or above; HIC, high-income countries; U-MICs means upper-middle-income countries; L-MIC means lower-middle-income countries.

Table 4-3 presents univariable and multivariable analyses of the association between sociodemographic correlates and meeting the TPA guideline. In the univariable analysis, all correlates demonstrated statistically significant associations with meeting the guidelines. The associations for all except parent education remained statistically significant in the multivariable analysis. Girls had significantly lower odds of meeting the guideline compared to boys (adjusted OR [aOR]=0.70, 95% CI=0.51–0.96). In addition, older children had significantly lower odds of meeting the guideline (aOR=0.50, 95% CI=0.34–0.75). Children had higher odds of meeting the guideline if they were rural residents (aOR=1.78, 95% CI=1.27–2.49) or from L-MICs (aOR=1.35, 95% CI=0.89–2.04). The U-MIC children were less likely to meet the guideline than those from HIC.

Table 4-3: Univariable and multivariable analysis of correlates of meeting the WHO TPA guideline based on the 11,500 step/day threshold in pre-school children

	Univariable			Multivariable[a]		
	OR	95% CI	P-value	OR	95% CI	P-value
Sex			0.032			0.026
Boys	1	Ref.		1	Ref.	
Girls	0.72	0.53, 0.97		0.70	0.51, 0.96	
Age group in years			<0.001			0.001
3.0 to 3.9	1	Ref.		1	Ref.	
4.0 to <5.0	0.44	0.30, 0.64		0.50	0.34, 0.75	
Education class			0.014			0.064
High	1	Ref.		1	Ref.	
Low	1.47	1.08, 2.00		1.38	0.98, 1.95	
Residential area			0.002			0.001
Urban	1	Ref.		1	Ref.	
Rural	1.62	1.19, 2.19		1.78	1.27, 2.49	
Country income			<0.001			<0.001
HIC	1	Ref.		1	Ref.	
Upper-MIC	0.59	0.41, 0.85		0.49	0.33, 0.72	
Lower-MIC	1.68	1.15, 2.45		1.35	0.89, 2.04	

Notes: OR, odds ratio; HIC, high-income countries; MIC, middle-income countries; Low education class means secondary/high school or below; High education class means tertiary education or above; *a* denotes all variables in the table fitted in the final model at once. All variables in the univariable model met the criteria for inclusion in the multivariable model (p<0.01).

Discussion

Main findings of this study

We found that less than one-third of the children aged 3-4 years from 17 countries met the WHO TPA guideline using the validated De Craemer et al.[11] threshold of at least 11,500 steps/day as measured by the *activ*PAL™. We also found that the odds of meeting the guideline were lower among girls and older children, and higher among rural residents and children from L-MICs.

What is already known on this topic

Overall, 30.9% of our sample achieved the TPA guideline. This finding is similar to a recent study involving six European countries, which found that 32.7% of the pre-schoolers aged 3-6 years met the guideline using the same step-count-based threshold.[15]

The estimated prevalence of adherence to the TPA guideline observed in the present study is higher than the prevalence observed by Huang and Lee (20%) in a sample of 114 pre-schoolers aged 3-6 years in Hong Kong.[16] Differences in adherence to the TPA guideline could be due to substantial discrepancies in the sample sizes and ages of the participants. The difference could also be due to the difference in samples with the previous one being a small sample from a highly-urbanised HIC (Hong Kong).[16] Higher proportions of children meeting the TPA guideline have been previously reported,[22,28] including in a systematic review and meta-analysis which found that 78% of 3-5-year-old children met the TPA guideline.[29] This difference may be explained by variations in the definition of TPA used in our study compared to studies included in the Bourke et al. review.[29] Studies in the review used physical activity duration and most of them applied the accelerometry cut-point described by Evenson et al.[30] (e.g., >100 counts per minutes) to define TPA, which may have led to a greater proportion of children in these studies meeting the guideline. Again, the authors[29] highlighted the high degree of variation in prevalence of meeting the guideline in the included studies which is likely to be due at least partly to variation in the methodology used to measure time spent in the behaviours. Additionally, the systematic review and meta-analysis[29] mainly included studies from HIC, which limits the generalisability of the findings in LMICs.

We found that boys were more likely to achieve the TPA guideline than girls. Similar differences in the proportion of boys and girls meeting the guideline based on the 11,500 steps/day threshold has been demonstrated in a previous study.[14] Sigmundova et al.[14] found that 47.4% of girls and 54.1% of boys met the 11,500 steps/day threshold in a sample of 194 pre-schoolers aged 4-7 years in Czech Republic. By contrast, a systematic review and meta-analysis did not find differences between boys and girls in meeting the 180 minutes/day in TPA.[29] We found a higher proportion of pre-schoolers from rural areas met the TPA guideline. This finding is consistent with previous research among older children in Mozambique.[26]

What this study adds

Understanding of the prevalence and sociodemographic correlates of adherence to the global TPA guideline in a geographically and culturally varied samples is an essential part of the Behavioural Epidemiology Framework.[6] The Framework is needed to identify whether there is a need to develop interventions, and which groups of children are most in need of intervention.[6] The present study suggests that only a minority of 3-4 year-olds might meet the WHO TPA guideline globally, with a lower proportion among girls than boys. Taken together, this finding suggests the need to include 3-4 year olds globally in surveillance of physical activity which is a gap in global surveillance at present.[5,31] If confirmed by other studies, the finding on sex disparity in meeting the TPA guideline also suggests the need to develop interventions to promote equal participation physical activity and enhance health equity in young children. We also observed that younger children were more likely to achieve the TPA guideline than older children. This suggests the need to promote lifelong participation in physical activities among older children to sustain the health benefits across the lifespan. Additionally, the sex differences in adherence to the TPA guideline further highlight the importance of implementing physical activity interventions that also include girls to promote equal and inclusive participation between girls and boys.

Our finding on urban/rural differences in meeting the TPA guideline contributes to the body of knowledge suggesting that urban residents may have, or choose, fewer opportunities for participation in habitual TPA and more options for sedentary activities. This may be the result of lifestyle differences and environmental opportunities and constraints (e.g., passive transportation and more screens).[32] In contrast, rural children may typically have more space, more outdoor time, more use of active transportation, more limited access to screens, and possibly more family chores which may facilitate children in meeting the TPA guideline.[26,32]

The present study identified key correlates associated with meeting the TPA guideline based on De Craemer et al's[11] threshold of 11,500 steps/day. We found that meeting the TPA guideline is related to sex, age, and residential area (urban/rural). In addition, our study revealed that meeting the guideline is also related to country-income level, with pre-schoolers from L-MICs having higher odds of meeting the WHO TPA guideline compared to children from HICs or U-MICs. We found that children from U-MICs had lower odds of meeting the guideline compared to those from HICs. It is plausible that urbanisation and modernisation might be influencing this finding. However, the finding for U-MICs is unexpected, and might be related to economic transitions occurring in those countries compared to HICs. Taken together, these findings draw our attention to the importance of considering varying contexts when planning interventions to promote increases in the prevalence of meeting the global TPA guideline in young children.

Limitations of this study

Our study has several limitations. Correlates identified in the present study are limited to the available correlates and most of them were parent-reported. Future studies could use a wider range of correlates drawn from the different levels of the Social Ecological Model,[33] including individual and environmental level correlates. Our sample was not representative due to non-standardised recruitment procedures across participating countries during the Pilot Phase of the SUNRISE Study,[17] which included the use of convenience cluster sampling. Furthermore, it should be noted that the observed prevalence and correlates in the present study may differ within and between countries due to cultural and geographical variations. However, smaller sample sizes for some countries in the present study (e.g., USA, n=5) limited our ability to explore country-level prevalence and correlates. Nevertheless, the pooled sample size used in the present study was both relatively large and novel in having a diverse international sample with adherence to the TPA guideline assessed using a validated and culturally appropriate device-based measure.[7] Such measures are currently lacking, thus limiting cross-country and global surveillance studies in young children.[5,31] Future larger studies using a standardised protocol are planned with more representative sample sizes around 1000 children per country as part of the SUNRISE Main Study initiative and these will provide more definitive evidence,[17] but studies like the present one show the need for such future larger studies focusing on cross-country variations.

Challenges experienced by children while wearing *activ*PAL™ have previously been reported (e.g., discomfort and irritation from the device placement on the thigh, skin rashes).[17] This may have affected the wear time compliance among participants which may have influenced the observed findings. However, our findings were similar to the European study[15] that used different devices and placements. As such, our findings may be generalisable across different devices and placements. The lack of participants from low-income countries (LIC) based on the World Bank classification adds further caution regarding the generalisability of these findings. Levels and correlates of physical activity may be different across different cultural contexts.[34] Nevertheless, our study included participants from five L-MICs, which are under-represented in most physical activity studies.[29] We used at least 1 valid day accelerometry data in our analyses (i.e., n=750 children with at least one valid weekday for a total of 1507 valid days and n=214 children with at least one valid weekend day data for a total of 349 valid days); however, a single day of observation is appropriate for surveillance studies which focus on providing group or population-level physical activity estimates.[35] Additionally, we calculated pooled prevalence estimates for meeting the TPA guideline, yet evidence from HIC suggests differences in physical activity patterns during weekdays and weekend days.[15] However, the present study included participants from MICs where it is not yet clear whether physical activity behaviour patterns in young children differ during weekdays and weekend days. Future cross-country studies should therefore examine prevalence and correlates of meeting the TPA guideline in young children during weekdays compared with weekends. Lastly, the WHO TPA guideline in 3-4 year olds includes MVPA recommendation, so further research that takes into account MVPA is needed.

This study also has important strengths including the use of a relatively large and globally diverse sample that adds to the limited literature and further our understanding of how step-counting could inform the WHO physical activity guideline in 3-4 year olds globally, including lower- and upper-MICs. The present study helps to fill an important gap in the literature by suggesting that the prevalence of meeting the global TPA guideline may differ by country income levels.[36] Another strength is the use of a validated step-based threshold corresponding to the 180 minutes/day of TPA which has been recommended for global monitoring of adherence to the WHO physical activity guideline in early childhood.[7] This will be important to inform public health interventions aimed to promote physical activity in young children globally.

Conclusion

This study set out to understand how step-counting can effectively inform the WHO physical activity guideline. We found that meeting the WHO TPA guideline may be relatively uncommon among 3-4 year-olds globally. Boys, younger children, and children from rural areas may have a higher prevalence of meeting the TPA guideline. These findings enhance our understanding of the value of simple device-based methods of measuring physical activity, and suggest that they might be useful in surveillance and in using the Behavioural Epidemiology Framework as it applies to physical activity in young children globally. The present study also suggests that interventions to promote and preserve adherence to the TPA guideline for the promotion of healthy growth and development in young children globally should consider the varying contexts around the world.

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Published article references

1. World Health Organization. *Report of the Commission on Ending Childhood Obesity*.; 2016.

2. Hills AP, Andersen LB, Byrne NM. Physical activity and obesity in children. *Br J Sports Med*. 2011;45:866-870. doi:10.1136/bjsports-2011-090199

3. Timmons BW, Leblanc AG, Carson V, et al. Systematic review of physical activity and health in the early years (aged 0-4 years). *Appl Physiol Nutr Metab*. 2012;37(4):773-792. doi:10.1139/H2012-070

4. Carson V, Lee E, Hewitt L, et al. Systematic review of the relationships between physical activity and health indicators in the early years (0-4 years). *BMC Public Health*. 2017;17(S5):854. doi:10.1186/s12889-017-4860-0

5. Reilly JJ, Aubert S, Brazo-Sayavera J, Liu Y, Cagas JY, Tremblay MS. Surveillance to improve physical activity of children and adolescents. *Bull World Health Organ*. 2022;100(12):815-824. doi:10.2471/BLT.22.288569

6. Sallis JF, Owen N, Fotheringham MJ. Behavioral epidemiology: A systematic framework to classify phases of research on health promotion and disease prevention. *Ann Behav Med*. 2000;22(4):294-298. doi:10.1007/BF02895665

7. Mwase-Vuma TW, Janssen X, Okely AD, et al. Validity of low-cost measures for global surveillance of physical activity in pre-school children: The SUNRISE validation study. *J Sci Med Sport*. 2022;25(12):1002-1007. doi:10.1016/j.jsams.2022.10.003

8. Guseh JS, Figueroa JF. Evaluating the Health Benefits of Low-Frequency Step-Based Physical Activity-The "Weekend Warrior" Pattern Revisited. *JAMA Netw open*. 2023;6(3):e235184. doi:10.1001/jamanetworkopen.2023.5184

9. Gabel L, Proudfoot NA, Obeid J, et al. Step count targets corresponding to new physical activity guidelines for the early years. *Med Sci Sports Exerc*. 2013;45(2):314-318. doi:10.1249/MSS.0b013e318271765a

10. Vale S, Trost SG, Duncan MJ, Mota J. Step based physical activity guidelines for preschool-aged children. *Prev Med (Baltim)*. 2015;70:78-82. doi:10.1016/j.ypmed.2014.11.008

11. De Craemer M, De Decker E, De Bourdeaudhuij I, Verloigne M, Manios Y, Cardon G. The translation of preschoolers' physical activity guidelines into a daily step count target. *J Sports Sci*. 2015;33(10):1051-1057. doi:10.1080/02640414.2014.981850

12. Bassett DR, Toth LP, LaMunion SR, Crouter SE. Step Counting: A Review of

Measurement Considerations and Health-Related Applications. *Sport Med*. 2017;47(7):1303-1315. doi:10.1007/s40279-016-0663-1

13. De Craemer M, Lateva M, Iotova V, et al. Differences in Energy Balance-Related Behaviours in European Preschool Children: The ToyBox-Study. Published online 2015. doi:10.1371/journal.pone.0118303

14. Sigmundová D, Sigmund E, Badura P, Vokáčová J, Trhlíková L, Bucksch J. Weekday-weekend patterns of physical activity and screen time in parents and their pre-schoolers. Published online 2016. doi:10.1186/s12889-016-3586-8

15. Decraene M, Verbestel V, Cardon G, et al. Compliance with the 24-hour movement behavior guidelines and associations with adiposity in european preschoolers: Results from the toybox-study. *Int J Environ Res Public Health*. 2021;18(14). doi:10.3390/ijerph18147499

16. Huang WY, Lee EY. Comparability of activPAL-based estimates of meeting physical activity guidelines for preschool children. *Int J Environ Res Public Health*. 2019;16(24). doi:10.3390/ijerph16245146

17. Okely AD, Reilly JJ, Tremblay MS, et al. Cross-sectional examination of 24-hour movement behaviours among 3- and 4-year-old children in urban and rural settings in low-income, middle-income and high-income countries: the SUNRISE study protocol. *BMJ Open*. 2021;11(10):e049267. doi:10.1136/bmjopen-2021-049267

18. De Decker E, De Craemer M, Santos-Lozano A, Van Cauwenberghe E, De Bourdeaudhuij I, Cardon G. Validity of the ActivPAL™ and the ActiGraph monitors in preschoolers. *Med Sci Sports Exerc*. 2013;45(10):2002-2011. doi:10.1249/MSS.0b013e318292c575

19. De Craemer M, De Decker E, Santos-Lozano A, et al. Validity of the Omron pedometer and the actigraph step count function in preschoolers. *J Sci Med Sport*. 2015;18(3):289-293. doi:10.1016/j.jsams.2014.06.001

20. Aminian S, Hinckson EA. Examining the validity of the ActivPAL monitor in measuring posture and ambulatory movement in children. *Int J Behav Nutr Phys Act*. 2012;9:1-9. doi:10.1186/1479-5868-9-119

21. Santos R, Zhang Z, Pereira JR, Sousa-Sá E, Cliff DP, Okely AD. Compliance with the Australian 24-hour movement guidelines for the early years: Associations with weight status. *BMC Public Health*. 2017;17(Suppl 5). doi:10.1186/s12889-017-4857-8

22. Dias KI, White J, Jago R, et al. International comparison of the levels and potential correlates of objectively measured sedentary time and physical activity among three-to-

four-year-old children. *Int J Environ Res Public Health*. 2019;16(11). doi:10.3390/ijerph16111929

23. Bonita R, de Courten M, Dwyer T, Jamrozik K, Winkelmann R. Surveillance of risk factors for noncommunicable diseases: The WHO STEPwise approach. Summary. Published online 2001.

24. Vanderauwera J, van Setten ERH, Maurits NM, Maassen BAM. The interplay of socio-economic status represented by paternal educational level, white matter structure and reading. *PLoS One*. 2019;14(5):e0215560. doi:10.1371/JOURNAL.PONE.0215560

25. The World Bank. World Bank country and lending groups. Accessed August 20, 2023. https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups

26. Manyanga T, Barnes JD, Chaput JP, Katzmarzyk PT, Prista A, Tremblay MS. Prevalence and correlates of adherence to movement guidelines among urban and rural children in Mozambique: A cross-sectional study. *Int J Behav Nutr Phys Act*. 2019;16(1):1-12. doi:10.1186/s12966-019-0861-y

27. Tabachnick BG, Fidell LS. *Using Multivariate Statistics*. 6th ed. Pearson Education, Inc.; 2014.

28. De Craemer M, Lateva M, Iotova V, et al. Differences in Energy Balance-Related Behaviours in European Preschool Children: The ToyBox-Study. *PLoS One*. 2015;10(3):e0118303. doi:10.1371/journal.pone.0118303

29. Bourke M, Haddara A, Loh A, Carson V, Breau B, Tucker P. Adherence to the World Health Organization's physical activity recommendation in preschool-aged children: a systematic review and meta-analysis of accelerometer studies. *Int J Behav Nutr Phys Act 2023 201*. 2023;20(1):1-15. doi:10.1186/S12966-023-01450-0

30. Evenson KR, Catellier DJ, Gill K, Ondrak KS, McMurray RG. Calibration of two objective measures of physical activity for children. *J Sports Sci*. 2008;26(14):1557-1565. doi:10.1080/02640410802334196

31. Aubert S, Brazo-Sayavera J, González SA, et al. Global prevalence of physical activity for children and adolescents; inconsistencies, research gaps, and recommendations: a narrative review. *Int J Behav Nutr Phys Act*. 2021;18(1):1-11. doi:10.1186/s12966-021-01155-2

32. Kariippanon KE, Chong KH, Janssen X, et al. Levels and Correlates of Objectively Measured Sedentary Behavior in Young Children: SUNRISE Study Results from 19 Countries. *Med Sci Sports Exerc*. 2022;54(7):1123-1130.

doi:10.1249/MSS.0000000000002886

33. Sallis JF, Owen N, Fisher EB. Ecological models of health behaviour. In: Glanz K, Rimer BK, Viswanath K., eds. *Health Behavior and Health Education: Theory, Research, and Practice*. 4th ed. ; 2008:465-485.

34. Miller JM, Pereira MA, Wolfson J, Laska MN, Nelson TF, Neumark-Sztainer D. Are Correlates of Physical Activity in Adolescents Similar Across Ethnicity/Race and Sex: Implications for Interventions. *J Phys Act Heal*. 2019;16(12):1163-1174. doi:10.1123/JPAH.2018-0600

35. Burchartz A, Anedda B, Auerswald T, et al. Assessing physical behavior through accelerometry – State of the science, best practices and future directions. *Psychol Sport Exerc*. 2020;49:101703. doi:10.1016/j.psychsport.2020.101703

36. Carson V, Draper CE, Okely A, Reilly JJ, Tremblay MS. Future Directions for Movement Behavior Research in the Early Years. *J Phys Act Heal*. 2024;21(3):218-221. doi:10.1123/jpah.2023-0679

4.4 Preface references

1. De Craemer M, De Decker E, De Bourdeaudhuij I, Verloigne M, Manios Y, Cardon G. The translation of preschoolers' physical activity guidelines into a daily step count target. *J Sports Sci*. 2015;33(10):1051-1057. doi:10.1080/02640414.2014.981850

2. Sallis JF, Owen N, Fotheringham MJ. Behavioral epidemiology: A systematic framework to classify phases of research on health promotion and disease prevention. *Annals of Behavioral Medicine*. 2000;22(4):294-298. doi:10.1007/BF02895665

3. Carson V, Draper CE, Okely A, Reilly JJ, Tremblay MS. Future Directions for Movement Behavior Research in the Early Years. *J Phys Act Health*. 2024;21(3):218-221. doi:10.1123/jpah.2023-0679

4. Barrera M, Castro FG, Strycker LA, Toobert DJ. Cultural Adaptations of Behavioral Health Interventions: A Progress Report. *J Consult Clin Psychol*. 2012;81(2):196. doi:10.1037/A0027085

5. Nusurupia J, J. RJ, Xanne J. Pre-school children's compliance with the WHO 24-hour movement behaviour guidelines: a systematic review of Sub-Saharan African studies. *African Journal for Physical Activity and Health Sciences (AJPHES)*. 2020;26(4):345-359. doi:10.10520/ejc-ajpherd1-v26-n4-a2

6. Arts J, Drotos E, Singh AS, Chinapaw MJM, Altenburg TM, Gubbels JS. Correlates of Physical Activity in 0- to 5-year-olds: A Systematic Umbrella Review and Consultation of International Researchers. *Sports Medicine*. 2023;53(1):215-240. doi:10.1007/s40279-022-01761-5

7. Feng J, Zheng C, Sit CHP, Reilly JJ, Huang WY. Associations between meeting 24-hour movement guidelines and health in the early years: A systematic review and meta-analysis. *J Sports Sci*. 2021;39(22):2545-2557. doi:10.1080/02640414.2021.1945183

8. Tapia-Serrano MA, Sevil-Serrano J, Sánchez-Miguel PA, López-Gil JF, Tremblay MS, García-Hermoso A. Prevalence of meeting 24-hour movement guidelines from pre-school to adolescence: A systematic review and meta-analysis including 387,437 participants and 23 countries. *J Sport Health Sci*. 2022;11(4):427-437. doi:10.1016/j.jshs.2022.01.005

9. World Health Organization. *World Health Organisation Guidelines for Physical Activity, Sedentary Behaviour, and Sleep for Children under 5 Years of Age*.; 2019. Accessed March 13, 2024. https://www.who.int/publications/i/item/9789241550536

10. Abdeta C, Cliff D, Kariippanon K, et al. Adherence to the WHO physical activity, screen time and sleep guidelines and associations with socio-demographic factors among

Ethiopian preschool children: The SUNRISE study. *Journal of Activity, Sedentary and Sleep Behaviors*. 2024;3(1):22. doi:10.1186/s44167-024-00060-w

11. Chong KH, Suesse T, Cross PL, et al. Pooled Analysis of Physical Activity, Sedentary Behavior, and Sleep Among Children From 33 Countries. *JAMA Pediatr*. 2024;178(11):1199. doi:10.1001/jamapediatrics.2024.3330

12. Adamo KB, Prince SA, Tricco AC, Connor-Gorber S, Tremblay M. A comparison of indirect versus direct measures for assessing physical activity in the pediatric population: A systematic review. *International Journal of Pediatric Obesity*. 2009;4(1):2-27. doi:10.1080/17477160802315010

13. Phillips SM, Summerbell C, Hobbs M, et al. A systematic review of the validity, reliability, and feasibility of measurement tools used to assess the physical activity and sedentary behaviour of pre-school aged children. *International Journal of Behavioral Nutrition and Physical Activity*. 2021;18(1):1-28. doi:10.1186/s12966-021-01132-9

14. Cardon G, De Bourdeaudhuij I. Comparison of Pedometer and Accelerometer Measures of Physical Activity in Preschool Children. *Pediatr Exerc Sci*. 2007;19:205-214. doi:https://doi-org.proxy.lib.strath.ac.uk/10.1123/pes.19.2.205

15. Oliver M, Schofield GM, Kolt GS. Physical Activity in Preschoolers: Understanding Prevalence and Measurement Issues. *Sports Medicine*. 2007;37(12):1045-1070. doi:10.2165/00007256-200737120-00004

16. Reilly JJ, Aubert S, Brazo-Sayavera J, Liu Y, Cagas JY, Tremblay MS. Surveillance to improve physical activity of children and adolescents. *Bull World Health Organ*. 2022;100(12):815-824. doi:10.2471/BLT.22.288569

17. Ding D, Chastin S, Salvo D, et al. Realigning the physical activity research agenda for population health, equity, and wellbeing. *The Lancet*. 2024;6736(24):4-6. doi:10.1016/S0140-6736(24)01540-X

18. Okely AD, Reilly JJ, Tremblay MS, et al. Cross-sectional examination of 24-hour movement behaviours among 3- and 4-year-old children in urban and rural settings in low-income, middle-income and high-income countries: the SUNRISE study protocol. *BMJ Open*. 2021;11(10):e049267. doi:10.1136/bmjopen-2021-049267

19. Kang H. The prevention and handling of the missing data. *Korean J Anesthesiol*. 2013;64(5):402-406. doi:10.4097/kjae.2013.64.5.402

20 Austin PC, White IR, Lee DS, van Buuren S. Missing Data in Clinical Research: A Tutorial on Multiple Imputation. *Canadian Journal of Cardiology*. 2021;37(9):1322-1331. doi:10.1016/j.cjca.2020.11.010

21 Tremblay MS. Challenges in global surveillance of physical activity. *Lancet Child Adolesc Health*. 2020;4(1):2-3. doi:10.1016/S2352-4642(19)30348-7

22 Reilly JJ, Aubert S, Brazo-Sayavera J, Liu Y, Cagas JY, Tremblay MS. Surveillance to improve physical activity of children and adolescents. *Bull World Health Organ*. 2022;100(12):815-824. doi:10.2471/BLT.22.288569

Chapter 5: Prevalence and correlates of meeting World Health Organization 24-hour movement guidelines among 3–4-year-olds in Malawi: The cross-sectional SUNRISE Malawi study

5.1 Preface

This chapter describes evidence generated through primary data collection in Malawi to address the lack of evidence on 24-hour movement behaviours in the early years from a low-income SSA context. This chapter contains a manuscript "Prevalence and correlates of meeting World Health Organization 24-hour movement guidelines among 3–4-year-olds in Malawi: The cross-sectional SUNRISE Malawi Study" was submitted to and is currently under review in the *Journal of Physical Activity and Health.*

5.1.1 Chapter introduction and rationale

The previous chapters (Chapters 3 and 4) presented secondary analyses of cross-sectional data from two pilot phases of the SUNRISE International Study to address two critical gaps in the global literature: (1) the lack of evidence on simple, practical, and valid methods that are culturally appropriate for assessing physical activity in young children to inform surveillance systems and promote equitable movement behaviour research globally; and (2) the limited evidence on compliance with the global 24-hour movement behaviour guidelines among young children in LMICs globally,[1–5] particularly in SSA, generated using valid, practical, and culturally appropriate methods. Chapter 4 showed that compliance with the global 24-hour movement behaviour guidelines in young children varies by country income level (middle- vs high-income). However, these findings may not be generalisable to low-income contexts, as the evidence presented in Chapter 4 was limited to middle- and high-income countries.

As previously noted, there was very little evidence on the prevalence and correlates of meeting the global guidelines among young children in SSA at the time the work presented in this thesis began. The available evidence was from small pilot studies conducted in MIC settings,[6] with no data from LICs. By the time of writing this thesis, two studies had reported evidence from low-income SSA.[7,8] However, both studies relied on expensive and complex methods for assessing 24-hour movement behaviours (e.g., accelerometry-based activity duration), which may have limited practical utility for large-scale surveillance studies in resource limited settings globally, particularly in low-income SSA. The findings from the secondary analysis in Chapter 4 warrant investigating compliance with the global movement behaviour guidelines among young children in Malawi using simple, cheap, and culturally appropriate methods, as validated in Chapter 3.

This chapter aimed to determine the prevalence and identify sociodemographic correlates of meeting the global 24-hour movement guidelines in 3–4 year olds in Malawi. This involved implementing the SUNRISE International Study protocol[5] in Malawi. While a detailed description of the methodological approach used in this chapter is included in the submitted manuscript provided later in this chapter (*Section 5.3*), the following section expands on the methodology for primary data collection in Malawi.

5.1.2 Methodology for primary data collection in Malawi

5.1.2.1 Malawi context

Malawi was the second low-income SSA country to join the SUNRISE International Study in 2020 and implemented Phase 3 study protocol. Geographically, Malawi is a landlocked country located in south-eastern Africa. It is bordered by Tanzania to the northeast, Zambia to the northwest, and Mozambique to the east, south and west (*Figure 5-1*). The country is geographically and administratively divided into three regions, namely northern, central and southern regions. In addition, there are 28 districts and four major cities in Malawi. The four cities include Mzuzu city in the northern region, Lilongwe city in the central region, and Blantyre and Zomba cities in the southern region.

As summarised in *Table 5-1*, the population of Malawi was 17.6 million in 2018,[9] of which 51% were female and 49% were male. The 2018 Malawi population almost doubled compared to the 1998 population. Children under five years constitute 15% of the population while the majority (49%) are aged 18 years or older and very few (4%) are 65 years or older.[9] Eighty-four percent of the population live in rural areas while 16% live in urban areas. The key demographic, socioeconomic, health, and technological indicators relevant to this thesis are summarised in *Table 5-1*.

There are clearly defined administrative jurisdiction for urban and rural settings in Malawi. Urban settings include the four major cities (i.e., Blantyre, Lilongwe, Mzuzu, and Zomba), other towns, and gazetted town planning areas.[9] As can be seen from *Table 5-1*, significant socioeconomic disparities exist between urban and rural settings in Malawi, with rural areas having high poverty levels, low literacy levels, limited access to electricity and electronic devises in rural compared to the urban settings.[13,15,18]

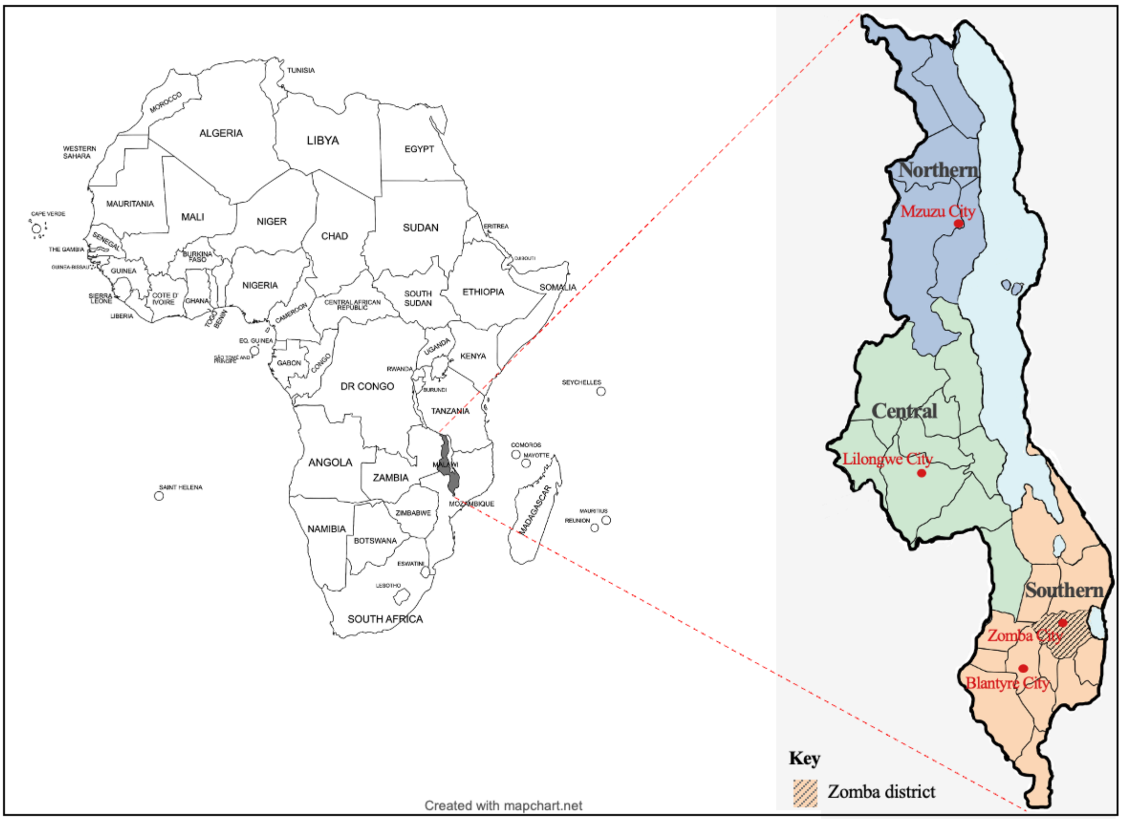

Figure 5-1: Map showing the geographic location of Malawi within the African continent (left) and a detailed view of Malawi's administrative regions (right). The map highlights Malawi's three regions (Northern, Central, and Southern), major cities (Mzuzu, Lilongwe, Zomba, and Blantyre), Lake Malawi on the eastern border, and Zomba district, the study site, in the Southern Region. (Note: The author created the maps using ChartMap and customised them using Microsoft PowerPoint).

Table 5-1: Key demographic, socioeconomic, health, and technological indicators for Malawi

Indicator	Malawi	Urban	Rural
Demographic indicators			
Population (2018)[9]	17.6 million	2.8 million	14.8 million
Under 5s (2018)	2.6 million	0.4 million	2.2 million
Urban population (2018)[9]	16.0%		
Annual urban population growth[10]	4.2%		
Socioeconomic indicators			
GDP per capita (in USD; 2023)[11]	$602.3		
Country income group[12]	Low		
Poverty rate (2022)[13]	58.8%	20.0%	65.7%
Attendance at ECD programmes (percent of 3–4 year olds; 2019-2020)[14]	34%	51%	31%
Adult literacy rate[a] (15 years and older)[15]	75.5%	98.1%	72.1%
Health indicators			
Under-5 mortality rate (per 1,000 live births; 2024)[16]	48		
NCD mortality (percent of all deaths; 2019)[17]	43%		
Technological indicators			
Household internet access (2023)[18]	18.4%	44.7%	13.6%
Household access to electricity (2023)[19]	25.5%	-	-
National grid	11.3%	56.5%	3.8%
Off-grid (mostly solar and rechargeable battery)	14.6%	6.5%	15.9%
Household ownership of functional television (2023)[18]	10.9%	38.5%	5.9%
Household ownership of mobile phones (2023)[18]	44.3%	63.6%	41.2%
Household ownership of a computer (2023)[18]	3.3%	14.2%	1.3%

Notes: a Adult literacy rate is defined as `the ability to read write a simple sentence in any language' (p. 22)[15]; GDP: Growth domestic product; USD: United States dollar; ECD: Early childhood development; NCD: Non-communicable diseases.

Figure 5-2: An aerial view of a small Malawian rural village on a hillside terrain. The image features a cluster of traditional thatched- and metal roof dwelling houses and agricultural plots typical of rural farming communities in Malawi. (Image by [Graham Hobster]() from [Pixabay](), 10 June 2017)

Figure 5-3: An aerial view of an urban landscape of Blantyre, Malawi's commercial city located in the southern region. (*Image by [Winnie Nyondo]() from [Facebook](), 25 December 2024)*

5.1.2.2 Study setting: Zomba district in southern Malawi

Data collection was conducted in the urban and rural settings of Zomba district, which is located about 300 kilometres from Malawi's capital city, Lilongwe (*Figure 5-1*). As per the SUNRISE International Study protocol,[5] Zomba district was purposefully selected because it is where the researcher is based, hence located within reasonable travel distance that ensured efficient data collection. Participants were recruited from ECEC centres in the urban (Zomba City) and rural (Zomba Rural) settings of Zomba district.

5.1.2.3 Sample size determination

The sample size for the present study was partially informed and guided by the sample size calculations for the SUNRISE International Study.[5] As previously mentioned, the SUNRISE study protocol requires a sample size for the main study of 1000 3- and 4-year old children in equal numbers by sex (i.e., 500 boys and girls each) and residential settings (i.e., 500 urban and rural each). However, the present study targeted 400-500 3–4 year olds based on what was funded by the Sir Halley Stewart Trust but also backed up by the sample size calculation below. The sample was determined using the following formula for calculating sample size for proportions when the population is infinite[20]:

$$n = \frac{Z^2 P(1-P)}{d^2}$$

Where *n* is the required sample size, Z is the statistic for a level of confidence, set at 1.96 corresponding to 95% confidence interval, *P* is the expected proportion of meeting all 24-hour movement behaviour guidelines of 26% (i.e., $P = 0.26$) based on a similar study in South Africa[21] determined at the start of this thesis work due to the lack of data from Malawi or similar context,[6] and *d* is the precision which was set at 5% (i.e., 0.05).[20] This resulted in a required sample size of 296 children. However, accounting for 20% refusal and/or failure to provide complete data, a target sample of 355 children was required, which was rounded upwards to 360 for both urban and rural settings. Since children were recruited from ECEC centres, a maximum of 25 children per centre was required to ensure variability within the sample in line with the SUNRISE International Study protocol.[5]

A total of 417 children were recruited from urban (n=100) and rural (n=317) settings during the pilot (n=57) and main study (n=360) data collection in Malawi. The sample distribution deviated from the SUNRISE protocol[5] as we oversampled from rural ECEC centres to broadly reflect the urban/rural population distribution and socioeconomic backgrounds in Malawi (i.e., most Malawians live in rural areas and are poor).[9]

5.1.2.4 Training of data collectors

Prior to the start of recruitment and data collection, three research staff underwent training on standardised protocol facilitated by the SUNRISE Coordinating Centre staff. The two-day training in preparation for pilot data collection was conducted in December 2021 via Zoom Workplace (Zoom Video Communication, Inc.) due to the COVID-19 travel restrictions that limited in-person training. Key components of the training relevant to the body of work in this thesis are presented in *Table 5-2* below.

Table 5-2: Key training components for the standardised training on the SUNRISE International Study protocol

	Training component
Day 1	• Background of study. • Roles and responsibilities of data collectors. • Parent information sheets and consent forms, assessment of 24-hour movement behaviours using accelerometry. • Assessment of anthropometry (height and weight). • Parent/caregiver questionnaire. • Centre information questionnaire. • Data entry, checking, and uploading to a secure server based at the SUNRISE Coordinating Centre at the University of Wollongong and accessible by the researcher.
Day 2	• Practice session for all assessments. • Debrief

As highlighted in *Table 5-2* above, the first day of training focused on familiarisation with the protocol, including presentations on and/or review of the aforementioned components. The three research staff that participated in the training were provided with relevant equipment, training manuals covering all components of the trainings, and links to relevant training videos on the SUNRISE International Study YouTube channel (https://www.youtube.com/@sunriseinternationalstudyo4800). The equipment were shipped from the University of Wollongong before the training dates.

The second day of the training focused on practising all assessments with three 3–4 year olds and their parents that were identified by the research staff. With consent from parents, each trainee was videoed while administering each assessment with children. The videos were shared with the Coordinating Centre staff for their review and feedback. After the practice session and a training debrief meeting, each research staff completed an online quiz on *Kahoot!*, an online game-based platform, to assess their understanding of the SUNRISE study protocol and data collection measurements. After reviewing responses from the online quiz, the Coordinating Centre staff arranged a follow-up training with the Malawi team on components that were not fully understood (e.g., anthropometric assessments) during the initial training session. The research staff also participated in a refresher training that was conducted after completing the initial pilot data collection, and these were also conducted as required throughout the main study data collection period. Subsequent refresher trainings were conducted by the PhD student (author), who also benchmarked the two other research staff and participated in all recruitment and data collection activities, as described in the following session.

5.1.2.5 Recruitment and data collection

Healthy children and their parents were recruited through ECEC centres in the urban and rural settings of Zomba district, as earlier mentioned. The recruitment of centres and participants was conducted throughout the school year to minimise the potential effects of seasonality on compliance with the global 24-hour movement behaviour guidelines among young children. A detailed description of participant recruitment and data collection procedures is provided in the submitted manuscript presented later in this chapter (*Section 5.3*). Briefly, a list of centres was obtained from relevant welfare offices in Zomba district. This was used to identify and select centres with at least 40 registered children aged 3 and 4 years who were eligible for participation.

Children were eligible to participate in the study if they were aged 3–4 years and could wear an accelerometer.[5] As previously mentioned, a maximum of 25 children were required per centre. As such, a minimum of 40 eligible children enrolled at each ECEC centre was required to ensure an adequate number of participating children and that data were collected from 20 children per ECEC centre on average.[5]

Centre directors were contacted by phone to confirm the number of eligible children, and the research team visited each centre to explain the study and assessments and to obtain centre consent. Since we targeted to recruit more children from the rural settings to align with the population distribution in Malawi,[9] a total of 8 urban centres and 16 rural centres were recruited, with an average of 13 and 20 children per centre, respectively (an overall average of 17 children per centre). All consenting ECEC centres were recruited for participation in the study. Once centres had consented, eligible children were identified and informed consent was obtained from their parents/caregivers before the start of data collection.

The parental questionnaire and informed consent forms were translated into Chichewa language that is widely spoken in Malawi to ensure standardised interviews and ensure that questions were applicable to the local context. The translated questionnaire and consent forms were used for data collection. These tools were pre-tested to ensure clarity of the translations, and any inconsistencies were resolved by the research team before the start of data collection. In line with the SUNRISE International Study protocol,[5] pilot data collection (n=57) was conducted to assess the feasibility and acceptability of the protocol, as well as to resolve any methodological issues, including approaches to recruitment of centres and eligible children.

One major concern during recruitment was that some parents associated the accelerometers with witchcraft, as these electronic devices (or monitors) were relatively new for physical activity data collection in Malawi. Consequently, cultural appropriateness, operationally defined as the degree to which measurement protocols aligned with local customs, values, and beliefs, was a major consideration throughout the pilot (and intermediate) study implementation in Malawi. To address these concerns, the research team: (1) worked closely with ECEC staff as advocates, who also ensured children wore the monitors correctly during their attendance at the ECEC centres; (2) conducted demonstrations for parents during information sessions, particularly for those in rural settings, on wearing the monitors and clarified any misconceptions about the activity monitors; and (3) provided parents of participating children, particularly in urban settings, with a letter containing instructions in the local language for wearing the monitors, including the phone number of the researcher (author) in case they had questions or needed clarification. Additionally, the research team ensured all data collection instruments were translated into the local language (Chichewa) to enhance cultural appropriateness. Before recruiting participants, the research team obtained permission from relevant local government authorities (e.g., the District Commissioner and officials from the education and social welfare offices in Zomba district), who serve as 'gatekeepers,' and this permission facilitated access to participants. Overall, these measures enhanced the acceptability of the SUNRISE International Study protocol, with acceptability operationally defined as the participation rate of at least 80% (82% in the Malawi study).

Furthermore, the pilot study helped to estimate the duration of all assessments per child, which was then used to plan data collection schedules during the intermediate study. The PhD student (author) led the recruitment of ECEC centres and participants and data collection for both the pilot and intermediate studies.

Pilot data collection was conducted between February and July 2022 and the intermediate study (n=360) was conducted between August 2022 and May 2023. While the prolonged data collecting period allowed for the collection of seasonal data to assess its influence on children's movement behaviours, data collection was hampered at times by a number of adverse events. These included: (1) two major storms (Tropical Cyclones Ana and Freddy) that devastated southern Malawi in early 2022 and 2023, causing flooding, travel disruption, and closure of schools; (2) fuel shortages due to the scarcity of foreign currency (US dollars) for importation; and (3) a cholera outbreak that resulted in the temporary closure of schools in the southern region.

5.1.2.6 Measurement methods and procedures

As outlined in the SUNRISE protocol[5] and specific to the thesis work presented in this chapter, several measurement methods were used during primary data collection in Malawi. These methods are summarised in *Table 5-3,* and details provided in the submitted manuscript presented later in this chapter (*Section 5.3*). *Figure 5-4* illustrates key procedures implemented during primary data collection in Malawi, which are briefly described below. *Appendix L* contains a figure that illustrates additional measurements collected as part of the SUNRISE International Study protocol[5] which are not relevant to this thesis.

Accelerometers (or activity monitors) were fully charged and initialised using ActiLife 6 software (ActiGraph, Pensacola, FL, USA) to start recording from midnight of the first day of data collection (i.e., at 00:00:00 hours). Upon arrival at the ECEC centre, the research team and centre staff jointly identified children whose parents had consented for their participation. The three trained research staff each administered the assessments to each child one at a time, starting with placing the accelerometer on the child's waist and then taking anthropometric measurements (height and weight) as per the study protocol.[5] Anthropometric measurements and the serial number of the accelerometer were recorded against each child's record in the REDCap Mobile App[22] on iPads. Children were asked to wear the accelerometers attached to an elastic belt for 5 consecutive days except during water-based activities,[5] and they were advised to take care of their 'belt' and not to give it to anyone else.

An activity monitor log (*Appendix H*) and the instruction sheet (*Appendix I*) were given to parents/caregiver if they were present on the first day of data collection or left with the centre staff to give the participating child's parents/caregiver if they were not present, especially in urban centres. In addition, the centre staff were instructed to help in ensuring that each participating child was properly wearing the monitor during attendance to the ECEC centre. On the last day of data collection, the research staff visited the centre to collect the accelerometers and the completed monitor activity log for each child, as well as to administer the parent and centre questionnaires through interviews.

Face-to-face interviews were conducted with the participating child's parent or primary caregiver at the participating ECEC centres. In urban centres, interviews were mostly conducted through phone calls, especially when the parent or primary caregiver was not available for a face-to-face interview due to their other commitments (e.g., business or work). The research staff recorded responses from the questionnaire survey interviews directly into the REDCap mobile App on iPads. They also recorded completed activity log for each child into their respective REDCap record.

Table 5-3: Summary of methods used during primary data collection in Malawi

Data collection method	Purpose
1. ActiGraph accelerometers	Assessment of physical activity.
2. Portable stadiometer	Measuring child's height.
3. Portable scale	Measuring child's weight.
4. SUNRISE parent questionnaire [a]	Administered to parents as an interview to report the time their child spent in restrained sitting, sedentary screen, and sleep.
5. SUNRISE Centre questionnaire [b]	Administered through interview to ECEC centre directors or heads. The questionnaire was used to record the date, including month and year of data collection, that was used to determine the season when data collection occurred. It was also used to record the location of the ECEC centre that was used to determine child's residential setting (urban or rural).
6. Activity monitor log [c]	Given to parents to record their child's wake-up and bed-time, indicate child's daily attendance to the ECEC centre, and whether the child slept with the monitor on.
7. Activity monitor instruction sheet [d]	Instructions to parents on how to remove and put back the activity monitor.

Notes: a SUNRISE parent questionnaire provided in *Appendix C*; b SUNRISE Centre questionnaire provided in *Appendix D*; c Activity monitor log provided in *Appendix H*; d Activity monitor instruction sheet provided in *Appendix I.* ECEC = Early childhood education and care centre.

Figure 5-4: Procedures for recruitment and data collection in Malawi. (A) Data collector explaining study aims and objectives to parents of eligible children during an information session at a rural study site. (B) Child being fitted with an ActiGraph accelerometer on the first day of data collection. (C) Data collector (author) measuring a child's height. (D) Data collector conducting an interview with a parent of a participating child on the last day of data collection at the ECEC centre. (Photo credits: SUNRISE Malawi, 2022–2023. Image composition by the author).

5.1.2.7 Data management methods

Data management

Accelerometry data were downloaded from the monitors using ActiLife 6 software and uploaded to a secure server for storage and sharing with the SUNRISE Coordinating Centre staff. The Coordinating Centre staff conducted regular data quality checks throughout the data collection period and provided feedback to the Malawi research team to address the queries as appropriate. At the end of the data collection period, raw accelerometry data were processed following the standardised SUNRISE ActiGraph accelerometry data checking and analysis protocol (*Appendix J*). Accelerometry data were exported to Excel format for further cleaning and analysis. Accelerometry data from the pilot study were processed by the SUNRISE Coordinating Centre staff while data from the intermediate study were processed by the PhD student (author) with guidance from the supervisory team.

The PhD student (author) obtained REDCap data (i.e., parent questionnaire and anthropometric measurements) from the SUNRISE Coordinating Centre after data quality checks and verification processes were completed. The REDCap data were also in Excel format. The two datasets were imported into Stata/IC v.16.1 for Mac (StataCorp, College Station, Texas, USA), one at a time, for further cleaning and converted into a Stata file format. The datasets were merged using child's unique identification number that was assigned on the first day of data collection (see *Section 5.1.2.9* for details). Further data cleaning was conducted after merging the datasets, including assessing missing data and outliers (e.g., children aged <3.0 or >5.0 years).

Handling missing data

As noted above, all data were checked for missing values before analyses. Missing data is a "data value that is not stored for a variable in the observation of interest."[23] This most commonly occurs in any kind of research when values of certain variables are not recorded or measured for all participants in the sample.[24] If missing data is not handled properly, researchers may draw incorrect conclusions due to the reduced statistical power and biased estimates from the study.[23] For any research, missing data can be classified into three categories, as described in *Table 5-4*.

Data were considered to be missing completely at random (MCAR), as some participating children had missing data on the outcomes of interest because their parents did not respond to the questionnaire and had insufficient or no accelerometry data. One of the most commonly used method of handling missing data that meets the assumption of MCAR is "complete case analysis".[23,24] Thus, participants (n=7) with missing data on both parent-reported and accelerometry-measured outcomes were excluded in all statistical analyses. Similarly, the complete case analysis method was used for handling missing data on the independent variables (potential correlates) during inferential analyses.

Table 5-4: Classification of common types of missing data in research

Type of missing data	Description
1. MCAR	Occurs when the likelihood of data being absent is independent of both the specific value expected and the observed responses.
2. MAR	Occurs when the likelihood of missing responses is contingent upon the observed responses but is independent of the actual missing values that could have been obtained.
3. MNAR	Occurs when the missing data do not fall under the two categories (i.e., MAR or MCAR).

Notes: MCAR: missing completely at random; MAR: missing at random; MNAR: missing not at random. Austin et al.[24] and Kang et al.[23]

5.1.2.8 Data analysis methods

This chapter utilised both descriptive and inferential statistical analysis methods. A detailed description of these methods is provided in the submitted manuscript presented later in this chapter (*Section 5.3*). In summary, descriptive analyses were performed to describe characteristics of participants, and summary statistics were presented as means and standard deviation for continuous variables that were normally distributed and frequencies and percentages for categorical variables. Chi-square tests were used to determine group differences in the levels of meeting the global 24-hour movement behaviour guidelines. The association between depended and independent variables were assessed using logistics regression model. As appropriate, results for inferential statistical were presented with associated p-values and 95% confidence intervals. Statistical significance was determined at 5% (i.e., $p<0.05$).

5.1.2.9 Ethical considerations

As previously mentioned, the SUNRISE International Study protocol was reviewed and approved by the Human Research Ethic Committee of the University of Wollongong (Ref: 2018/044; *Appendix E*). In Malawi, the protocol was reviewed and approved by the University of Malawi Research Ethics Committee prior to the start of primary data collection (Protocol No.: P.05/21/65; *Appendix K*). Additionally, permission to conduct data collection in Zomba district was sought from relevant local government officials in the district before recruiting centres and participants.

Furthermore, ECEC centre directors or heads provided written informed consents before the start of recruitment and data collection at their respective centres. Parents/caregivers of eligible healthy children also provided written informed consent for themselves and their child's participation. Contents of the centre and parental consents included background and benefits of the study, participation and data collection procedures, risks and benefits of participation, usage of study data and findings, ethics approval, and contact information the research team and ethics committee in case participants need further information.

To ensure confidentiality of study participants, each child was assigned a unique identity number with a combination of country code (MW), centre number, and child number. For example, the first child recruited from centre number one was assigned MW0101. The child's unique number was linked to all assessments, including accelerometry data and REDCap records. In addition, all data analyses were conducted at an aggregate level to maintain participants' confidentiality.

5.2 Chapter significance and contribution to research

This chapter addresses a critical gap identified in Chapters 3 and 4 on the lack of evidence on 24-hour movement behaviours in young children from low-income SSA settings generated using feasible and culturally appropriate methods. While Chapter 4 revealed differences in physical activity patterns by country income level, those findings were limited to middle- and high-income countries, leaving uncertainty about compliance with movement guidelines in low-income contexts.

This chapter provides novel contribution to the global literature by providing comprehensive data on compliance with all four global movement behaviour guidelines in a low-income SSA setting. This establishes a baseline understanding of the movement behaviours in a previously under-researched population, thus providing evidence to inform tailored policy interventions in line with the Behavioural Epidemiology Framework.[2,25] This chapter also demonstrates the practical application of validated measurement methods identified in Chapter 3 within a low-resource setting, confirming their feasibility for population surveillance in these settings.

Beyond its academic contribution, evidence presented in this chapter has had direct impact through dissemination to local, regional, and national stakeholders in Malawi as earlier noted. These knowledge translation activities, funded by the University of Strathclyde/ISPF/SFC grant, engaged families, education practitioners, childhood welfare and health professionals, policymakers, and non-governmental organisations. The dissemination and co-creation activities with these stakeholders have informed future research directions (as discussed in Chapter 6 *Section 6.5*). This demonstrates the practical relevance of this work for child health policy and practice in Malawi. A detailed description is provided in the next chapter (Chapter 6) and the dissemination and impact activities report in *Appendix B*.

5.3 Submitted manuscript

As previously mentioned, this manuscript was submitted as original research to the Journal of Physical Activity and Health in October 2024 and is currently under review. The manuscript is presented in its current version after addressing comments from the reviewers.

Suggested citation

Mwase-Vuma TW, Janssen X, Okely AD, Kayange J, Chong KH, Cross P, Evance S, Reilly JJ. Prevalence and correlates of meeting World Health Organization 24-hour movement guidelines among 3–4-year-olds in Malawi: The cross-sectional SUNRISE Malawi Study. *J Phys Act Heal*. (Under Review)

Author contributions

I am the primary (first) author of this article. With inputs from my supervisors (JJR and XJ), I adapted the SUNRISE International Study protocol to the Malawian context and developed and submitted the protocol for ethics review and approval by the local ethics committee in Malawi (approval letter provided in *Appendix K*). I led the research team in Malawi and participated in all the recruitment and data collection activities. JK and SE contributed to data acquisition. I also led data management and cleaning supported by ADO, JK, KHC, and PC. I conducted all data analyses with inputs from my supervisors. Additionally, I drafted the first version of the manuscript and revised it based on inputs from all authors. JJR submitted the final version of the manuscript for publication. My supervisors and I jointly addressed comments from the reviewers. All authors approved the final version of the submitted manuscript in line with the International Committee of Medical Journal Editors authorship guidelines (https://www.icmje.org/recommendations/browse/roles-and-responsibilities/defining-the-role-of-authors-and-contributors.html).

Furthermore, JJR and XJ obtained funding that supported the work in this thesis. JJR also obtained funding to support impact and co-creation activities in Malawi. I led the impact activities in Malawi with support from JK.

Supplementary material

Supplementary material mentioned in this article is presented in *Appendix M* of this thesis.

Title: Prevalence and Correlates of Meeting World Health Organization 24-Hour Movement Guidelines Among 3–4-year-olds in Malawi: The Cross-Sectional SUNRISE Malawi Study

Author names:

Tawonga W. Mwase-Vuma[a,b], Xanne Janssen[a], Anthony D. Okely[c], Janine Kayange[b], Kar Hau Chong[c], Penny Cross[c], Seth Evance[b], and John J. Reilly[a]

Affiliations:

a. Department of Psychological Sciences and Health, University of Strathclyde, Glasgow G1 1QE, Scotland
b. Centre for Social Research, University of Malawi, Zomba, Malawi.
c. Faculty of the Arts, Social Sciences and Humanities, University of Wollongong, Wollongong, New South Wales NSW 2522, Australia.

Corresponding author:

John J. Reilly
Department of Psychological Sciences and Health
University of Strathclyde, Glasgow G1 1QE, Scotland
Email: john.j.reilly@strath.ac.uk
ORCID: https://orcid.org/0000-0001-6165-5471

Abstract

Background: Prevalence and correlates of meeting the 24-hour movement guidelines in 3- and 4-year-old children from low-income countries are largely unknown. This study assessed prevalence and correlates of meeting World Health Organization (WHO) movement behaviour guidelines in Malawi. **Methods:** This study included 417 3–4-year-olds, (49% boys) from urban and rural settings from Zomba district in Malawi. Participant's sociodemographic information were collected using a modified version of the WHO STEPS survey. Total physical activity (TPA) was assessed using step-counts from hip-worn ActiGraph accelerometers, and meeting the 3 hour/day TPA guideline was defined as average daily steps ≥11,500. Parent questionnaires were used to assess prevalence of meeting WHO guidelines for sedentary screen time (<1 hour/day), sleep duration (10-13 hours/day) and not being in restrained sitting for >1 hour at a time. Backward multivariable survey logistic regression was used to determine correlates of meeting guidelines. Potential correlates included sex, age, weight status, socio-economic status (parent education), urban vs rural setting, and season. **Results:** Prevalence of meeting all guidelines was 60% (CI 52-68). Prevalence of meeting the individual guidelines was: TPA 98% (95% CI 96-99); sleep duration 91% (87-93); restrained sitting 76% (95% CI 68-83); sedentary screen time 79% (95% CI 71-86). Children from urban settings had significantly lower odds of meeting all four movement guidelines compared to their rural counterparts (OR: 0.11, 95% CI: 0.04, 0.37). **Conclusions:** Prevalence of meeting the 24-hour movement guidelines was high relative to other countries, though the physical activity transition may be underway in urban areas. Public health policy should incorporate measures to preserve these healthy levels of movement behaviours as economic development progresses in Malawi.

Keywords

Movement behaviours; Step-counting; Pre-school; Low-income setting; Sub-Saharan Africa

Introduction

The 2019 World Health Organization (WHO) guidelines on physical activity, sedentary behaviour, and sleep for children aged below five years emphasised the importance of those behaviours for childhood health, growth, and development.[1]. The WHO recommends that children aged 3 to 4 years engage in total physical activity (TPA) for at least three hours per day including one hour per day in moderate-to-vigorous-intensity physical activity (MVPA), not be restrained for more than one hour at a time, have sedentary screen time of not more than one hour per day, and get at least 10 to 13 hours of good quality sleep per day.

Dumuid et al.[2] posited the importance of a whole 24-hour period, noting that the amount of time spent on one behaviour affects the others. The health benefits of the 24-hour movement behaviours among 3-4 year olds are well documented.[1,3–6] These health behaviours also track to some extent, influencing future health behaviours[7,8] and progress towards global targets for reductions in physical inactivity in adolescents.[9] Low-and middle-income countries (LMICs) generally do not have surveillance systems in children to monitor prevalence of meeting movement behaviour guidelines,[10,11] and surveillance is limited even in high-income countries.[12] A systematic review of movement behaviours in 3-4-year old Sub-Saharan African children in 2020 only found two small pilot studies, both from South Africa.[13] A recent global pooled analysis of 7017 3-4 year olds[14] found that only 14% met combined WHO 2019 guidelines for physical activity, screen time and sleep, but the dataset contained only 286 children from the WHO African region and only 54 of those were from Malawi (data from the pilot study prior to the present study). The first, and to-date only, large scale published study of adherence to the WHO 2019 guidelines in 3-4 year olds from the WHO-Africa Region also came in 2024, from Ethiopia. Abdeta et al.[15] reported in a sample of 430 Ethiopian children of mean age 4.2 years that 58% met the combined WHO Guidelines for physical activity, sleep (both measured by accelerometry) and screen time (measured by parent report).

The majority of Malawi's population (84%) live in rural settings characterised by poor quality road infrastructure, limited or no access to electricity and electronic devices, and motorised public transportation.[16,17] Malawi's goal is to transition into an upper-middle-income country by 2063 through industrialisation and urbanisation.[18] Future economic transition in Malawi is likely to result in rapid changes in lifestyles, the 'physical activity transition',[19] probably accompanied by increased prevalence of non-communicable diseases (NCDs).[20] The physical activity transition and associated NCDs burden occurs when people change their active lifestyles to lifestyles characterised by greater use of motorised transportation and increased use of electronic screen devices.[19]

Tackling the challenge of the physical activity transition will require a substantial expansion of physical activity and health research and surveillance capacity in early childhood from Africa.[21] Africa accounts for a large and growing proportion of the world's child population,[22] but systematic reviews, international collaborative studies and surveys, and editorials have repeatedly noted that childhood movement behaviours in Africa are grossly under-researched, and almost entirely excluded from public health surveillance.[10,11,13,20,21,23–25]

The Behavioural Epidemiology Framework outlines six systematic phases of research for planning of interventions to improve population health.[26,27] These include establishing links between behaviour and health, developing/validating methods, determining prevalence and identifying correlates, evaluating interventions, and translating research into practice. There is well established evidence of associations between 24-hour movement behaviours and health outcomes.[1,4–8,28,29] However, evidence on the correlates/determinants of the movement behaviours in 3-4 year olds is currently limited, in part because the 24-hour movement behaviour paradigm is relatively recent and the previous focus was largely on physical activity.[30]

An umbrella review of studies of physical activity in 0-5 year olds found few well-established correlates/determinants (other than boys typically being more active than girls), and a dearth of evidence from LMICs.[31] Abdeta et al.[15] tested whether age, sex and urban vs rural location were correlates of meeting the combined 2019 WHO Guidelines for physical activity, screen time, and sleep duration in 3-4 year olds from Ethiopia. However, our understanding of what influences the movement behaviours in 3-4 year olds from Africa remains extremely limited. This evidence gap makes it difficult to identify high risk groups and to develop evidence-informed tailored interventions. Since lack of human and financial resources are major barriers to surveillance of prevalence and correlates of the movement behaviours, particularly in the poorest countries in the world[20,32,33] the results from the present study are expressed in this manuscript using the least expensive/most accessible data collection methods available. These include step-counting for measurement of physical activity and parent-reporting of screen-time, sleep duration, and restrained sitting. Our previous validation work showed that step counting using a threshold of at least 11,500 steps/day is valid for assessing achieving at least 3 hours of TPA in 3-4 year olds from globally diverse countries,[33] making it a valid, practical, and culturally appropriate alternative option to more expensive accelerometry-based activity counts for large scale population based and surveillance studies globally.

Drawing upon the Behavioural Epidemiology Framework,[27] the present study therefore aimed to 1) describe the prevalence of meeting the 24-hour movement guidelines –operationalised here as TPA based on step counting, restrained sitting, sedentary screen time, sleep duration– among Malawian children aged 3-4 years and 2) explore the factors associated with meeting the guidelines. Results obtained from accelerometry-measured movement, obtained using the international SUNRISE Study protocol,[24] are provided for completeness in Supplementary File 1 (presented in *Appendix M* of this thesis) and in the Discussion.

Methods

Study Design and Participants

This was a cross-sectional study involving 3-4-year-olds and their parents or primary caregivers in Malawi conducted as part of the SUNRISE Study (https://sunrise-study.com/). SUNRISE Study design and methods have been published elsewhere.[24] Healthy children were recruited from early childhood education and care (ECEC) centres in the urban and rural settings of Zomba district in Malawi. ECEC centres included nursery schools or kindergartens in the urban setting and community-based ECEC centres in rural settings.

Malawi has clearly defined administrative districts defined as urban or rural. There are marked socioeconomic differences between urban and rural settings: 66% of people in rural communities live in poverty compared to 20% of their urban counterparts[34]; only 23% of people aged 15 years or older in rural settings had completed at least a primary school education compared to 61% in urban settings[17]; only 5% of rural households have access to electricity provided by the national grid compared to 46% of urban households[17]; and most rural households have limited access to mobile phones and television,[16] in contrast to most urban households. In the present study, urban participants were recruited from ECEC centres in Zomba City, while rural participants were recruited from ECEC centres in Zomba Rural.

Zomba district is in the Southern Region located about 300 km from the capital city, Lilongwe. We obtained a list of urban and rural ECEC centres from the local government social welfare offices responsible for overseeing early childhood development in Zomba district. Centres with at least 40 registered children were eligible for selection. This was to ensure that there were enough children available for selection at each centre while also accounting for non-participation. A total of 142 ECECs (35 urban and 107 rural) were available for selection. The research team contacted the directors of eligible ECECs by phone to confirm the number of children enrolled and attending on a regular basis, as well as to invite them to participate.

Data Collection

Data were collected by three research staff who were trained in the standardised SUNRISE Study protocol.[24] Study data were collected and managed using the Research Electronic Data Capture (REDCap) mobile app hosted at the University of Wollongong.[35] Ethical approval for the study was obtained from the Human Research Ethics Committee at the University of Wollongong (coordinating centre; 2018/044) and the University of Malawi Research Ethics Committee (P.05/21/65). Permission was obtained from relevant local government authorities in Malawi before the start of data collection. Informed written consents were obtained from respective ECEC centre directors prior to participant recruitment, and parents provided written consent for their own and their children's participation.

Data were collected at the ECEC centres during school days (usually Monday to Friday or occasionally Tuesday-Saturday if all eligible and consenting children had not been measured Monday-Friday, with Saturdays primarily serving as the last day to collect monitors) between February 2022 and May 2023 after COVID-19 restrictions were relaxed in Malawi. This allowed data collection over 12 months, and covered Malawi's two main seasons (Cool dry and Hot wet) minimising seasonal bias on the data while permitting the season to be examined as a correlate.

Measurements and Procedures

Physical activity measurement

Habitual TPA was assessed using hip-worn ActiGraph GT3X+/GT3X-BT triaxial accelerometers (ActiGraph, Pensacola, FL, USA) initialised to record steps and activity counts at a 30 Hz sampling rate starting from midnight on the day when the accelerometer was attached to the child. ActiGraph accelerometers have been validated for measurement of step-counting in children aged 4-6 years.[36] Children were asked to wear the accelerometer on the right hip for at least five consecutive 24-hour periods except during water-based activities (e.g., bathing/showering or swimming). Research staff fitted the devices in the morning of the first day of data collection at the ECEC centre. Research staff showed parents who attended the first day of data collection how to remove and put back the device on their child to ensure children wore them correctly. Parents, particularly those in urban settings, who were not present at the ECEC centre during the first day of data collection received an information letter with instructions on how to remove and put back the device. Centre staff were instructed to help monitor on daily basis that participating children were (correctly) wearing the device during their attendance at the ECEC centre. The research staff removed devices from participating children at the ECEC centre on the last day of data collection. Accelerometry data were downloaded, processed and analysed using ActiLife 6 software (ActiGraph, Pensacola, FL, USA) to obtain total daily step count for each child. We calculated the average step-count for each child with a minimum of three 24-hour periods of wear. Minor departures from the SUNRISE Study protocol publication, along with the reasons for them, are provided in Supplementary File 2 (available in *Appendix M* of this thesis).

Step counting has been validated for measurement of meeting the TPA guideline in 3-4 year olds globally, with a step count $\geq$11,500/day providing high specificity and sensitivity for the assessment of meeting the TPA guideline.[33] Step counting using the 11,500 steps/day threshold has also been shown to provide useful surveillance of physical activity in globally diverse samples of 3-4 year olds.[37] Step counting is likely to be more practical for future public health surveillance of physical activity in LMICs than accelerometry (e.g., using cheaper devices like pedometers).[33] Moreover, step counts are easily measured and understood by children and adults, making them useful for translating evidence into practice, unlike less intuitive accelerations or activity counts.[38–40]

Since ActiGraph-accelerometer measured movement as measured by the international SUNRISE Study protocol[24] is also of importance in addition to step counting, the summary data for accelerometry-derived habitual time spent in TPA, MVPA, are all provided in Supplementary File 1 (*Appendix M* of this thesis). The SUNRISE Study protocol involves measuring a number of other variables not reported here (e.g., cognitive measures, accelerometer measured time spent sedentary). They will be reported separately as they are not highly relevant to the focus of the present study and paper.

Restrained sitting, sedentary screen time, and sleep duration

Child's restrained sitting, sedentary screen time, and sleep duration were proxy reported by parent using the SUNRISE Study parent/caregiver questionnaire[24] completed as an interview with the research staff. Interviews used to administer the questionnaire were conducted either face-to-face at the ECEC, or by phone where a face-to-face interview was not practically possible, e.g., in the urban settings where it was not possible to meet with parents at the centre for a face-to-face interview due to their other commitments. The SUNRISE parent/caregiver questionnaire[24] was translated into the local language (Chichewa) to ensure that questions were consistent and applicable to the local context. During both face-to-face and phone interviews, the research staff read out the translated questions verbatim to participants to avoid introducing any interviewer bias. The research staff recorded responses directly onto the REDCap Mobile App[35] on iPads while offline, and the data was uploaded to the server once connected to the internet. On a regular basis, the SUNRISE coordinating centre staff checked the server data for data quality and reported any inconsistencies or missing data to the Malawi research team. Any inconsistencies or missing data were double-checked or data were collected again by the research staff when required. *Table 5-5* provides details on the questions and response options as well as outcome variables used in our analysis.

Table 5-5: Description of parent-reported movement behaviours included in the analysis

Variable	Question and response option	Processing and final variable used for analysis
Meeting restrained sitting guideline	In the past week, were there any days where the 3 or 4-year-old child who is participating in this study was restrained for more than one hour at a time in a stroller, car seat, a motorbike, or on a bicycle taxi, or wrapped on the back? (Yes/No)	Children were classed as meeting the restrained sitting guideline if parents reported that their child was not restrained for more than 1 hour at a time.
Meeting screen time guideline	On a 24-hour period in the past week, how much time did the 3 or 4-year-old child who is participating in this study spend using any electronic screen device such as a smart phone, tablet, video game, or watch television or movies, videos on the internet while they were sitting or lying down? Please record this as accurately as you can to the nearest minute.	Total screen time was estimated in hours and minutes. A dichotomous variable was created to indicate if children met the sedentary screen time guideline of no more than one hour per day.
Meeting sleep duration guideline	How many hours of sleep does this child get in a typical 24-hours day (including naps)?	Sleep duration was estimated in hours and minutes. A dichotomous variable was created to indicate if children met the sleep duration guideline of at least 10–13 hours per 24-hour period.

Notes: Variable definitions are based on the 2019 WHO Guidelines for Physical Activity, Sedentary Behaviour, and Sleep for Children under 5 Years of Age.[1]

Definitions of meeting WHO movement behaviour guidelines

Dichotomous variables were created to indicate if children met the TPA, restrained sitting, sedentary screen time, and sleep duration guidelines. Meeting the guidelines was defined as: an average of at least 11,500 steps/day, equivalent to 3 hours per day of TPA[33,40]; restrained sitting for <1 hour at a time; sedentary screen time for <1 hour/day; 10-13 hours/day sleep duration.

Potential correlates

Correlates are variables associated with health behaviours identified in cross-sectional studies. Since health behaviours are believed to be influenced by factors at all levels of the Socio-Ecological Model,[27] it is logical to examine potential correlates at multiple levels of the model, but this can be difficult practically. Reviews of correlates studies in 3-4 year olds show that most studies have tended to focus on individual (child) and family level correlates, and correlates of physical activity only, with limited attempts to include correlates of sedentary screen time, sleep duration, restrained sitting, combinations of the movement behaviours, correlates at higher levels of the Socio-Ecological Model,[41] and LMIC contexts.[31,42] The present study included a relatively large number of potential correlates compared to many previous studies,[14,15,31,42] included candidate correlates of all of the movement behaviours,[43] included the most common candidates identified in young children globally, and included all four of the behaviours (TPA, restrained sitting, sedentary screen time, sleep). Our six candidate correlates extended from individual biological and cultural factors (age; sex/gender; weight status), to higher level demographic correlates (socio-economic status, SES; urban vs rural residence) and a higher level environmental correlate (season).

We operationalised the six candidate correlates as follows: sex, age, weight status (body mass index (BMI) for age), SES (parent education), residential setting (urban or rural), and season. Participant's sociodemographic data were collected using a modified version of the WHO STEPS Survey.[44] Parents also reported their child's date of birth or age in complete years if child's date of birth was unknown. This was used to calculate child's age in complete years and categorised into two groups: 3 and 4 year olds. Child's weight and height were measured by the research staff at the centre. Weight was measured in kilograms using an electronic Seca 878 scale (Seca Deutschland, Hammer Steindamm 3-25, 22089 Hamburg, Germany) suitable for mobile use. Height was measured in cm using Seca 213 portable stadiometer (SECA, UK). Two height and weight measurements each were taken and the mean for the two measures was used for analysis. A third measurement was taken if the first two measurements differed by more than 0.5 cm and 0.25 kg, respectively. Child's age, weight and height were used to calculate BMI for age z-score using *zscore06* Stata command based on the WHO child growth standards for children 0–5 years.[45] BMI was categorised into four groups based on the WHO cut points[46]: underweight (<-2 standard deviation [SD]), healthy/normal weight (>=-2 SD to <=+1 SD),with overweight (>+1 SD), and with overweight/obesity (>+2 SD). In addition, parents reported the highest educational level completed (they were asked 'What is the highest level of parental/caregiver education completed by a member of your household?') and this was categorised into two: low SES (secondary or high school and below) or high SES (vocational or tertiary education and above).[47] Parental education level was used as proxy for SES as it is widely used in LMICs and linked to health outcomes.[48] Residential setting (urban/rural) was determined based on the location of the ECEC where children were recruited using data from the Malawi National Statistical Office.[49] Season was determined using the month of data collection based on the World Bank classification of seasons for Malawi: Cool dry (May to October) or Hot wet (November to April) season.[50]

Statistical Analysis

All data analyses accounted for study design with post-stratification weighting calculated based on child age from Malawi Census data[49] to produce representative estimates for 3-4 year olds. Children were included in the current analysis if they had at least three 24-hour periods of accelerometry data[24,51] and complete data on the parent-reported movement behaviours (restrained sitting, sedentary screen time, and sleep duration). Descriptive analyses were conducted to describe the characteristics of participants, and these were presented as means and standard errors (SE) for continuous data or numbers and percentages (%) for categorical data. We calculated weighted prevalence estimates and associated 95% confidence intervals (CI) of meeting the guidelines for the overall sample and each of the potential correlates.

We used survey logistic regression for binary outcomes to determine correlates of meeting the guidelines in two steps. First, we conducted univariable analysis with each of the six potential correlates (sex, age, BMI for age, education class, residential setting, and season). We combined underweight and healthy weight BMI categories in the logistic regression analyses because there were few underweight children (n=5). Potential correlates with at least marginally significant p-values (i.e., $p<0.10$) were retained for use in the multivariable analyses.[52] Next, we conducted multivariable analyses using the stepwise backward regression method to determine correlates of meeting the global guidelines. Analyses were conducted for each of the four movement behaviours (TPA, restrained sitting, sedentary screen time, and sleep) and for all the guidelines combined. Correlates were determined at 5% significance level (i.e., $p<0.05$). An overall p-value was obtained for correlates with more than two categories (e.g., BMI).

Given that most educated people (i.e., those with higher SES) are likely to reside in urban settings than rural settings,[17] we assessed the presence of collinearity between SES and residential setting using pairwise correlation coefficients (*r*), variance tolerance inflation factors (VIF), condition number (CN), and tolerance, with thresholds of >0.7, >10, >30, and <0.1 indicating evidence of multicollinearity, respectively.[53] Except for tolerance (0.627), the test results (*r*=0.640; VIF=1.59; CN=2.566) were within the acceptable thresholds indicating that there was no evidence of collinearity. However, we took a conservative approach based on practical consideration of all factors that would affect variance.[54] Thus, only residential setting was retained for use in the multivariable analyses if both SES and residential setting were statistically significant ($p<0.10$) in the univariable analyses.

Post-hoc power calculations were conducted to provide a tentative estimate of the minimum proportion of children meeting all four 24-hour movement guidelines. A sample size of 369 was adequate to detect a minimum prevalence of 27% of children meeting all 24-hour movement behaviours (including TPA, n=372) at the 5% significance level and 80% power, assuming a prevalence estimate of 21%.[24] We also calculated 95% confidence intervals for all prevalence estimates as a means of dealing with issues of power and sample size. For power to identify correlates, a minimum of 10 participants per potential correlate was recommended by Uijtdewilligen et al.[55] All data processing and statistical analyses were conducted in Stata/IC v.16.1 for Mac (StataCorp, College Station, Texas, USA).

Conduct and reporting of the present study followed STROBE Guidance.[56]

Results

Descriptive characteristics of participants

A total of 424 children aged 3-4 years from urban (n = 6) and rural (n = 18) ECEC centres participated in the study. Seven children were excluded because they had missing accelerometry and parent-reported data (*Figure 5-5*). During analyses of accelerometry-measured physical activity we excluded a further 45 children because they had less than three 24-hour periods of data (i.e., remaining analytical sample n=369).

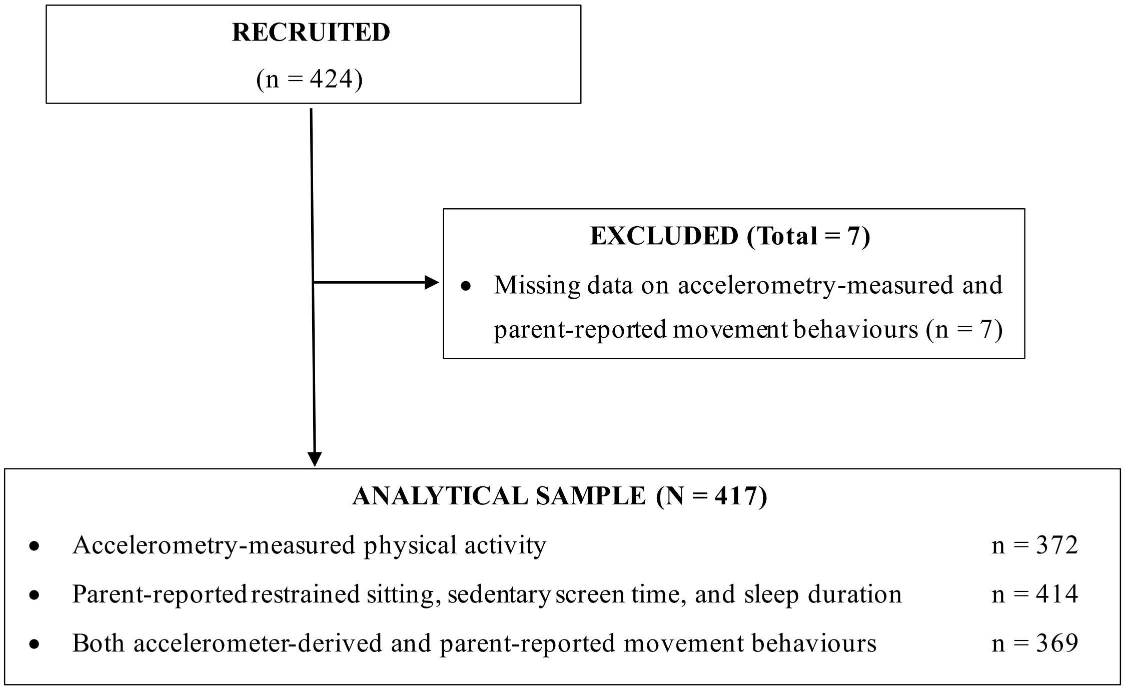

Figure 5-5: Flowchart detailing selection of the analytical sample. Accelerometry-measured physical activity refers to total physical activity based on step counting. Parent-reported movement behaviours include child's restrained sitting, sedentary screen time, and sleep duration.

A slight majority of the sample were girls (51.5%) and three-quarters lived in rural settings (75.9%), matching the population distribution for Malawi. Mean age was 4.0 years (SE: 0.0). As can be seen from *Table 5-6*, children were reported to sleep for an average of 11.2 hours per day (SE: 0.1) and accumulated an average steps/day of 24,269 (SE: 391). Children spent an average of 43 minutes/ day (SE: 7) in sedentary screen time and an average of 20 minutes/day (SE: 4) in restrained sitting.

Table 5-6: Descriptive characteristics of the included participants

	Number	Percent
Sex		
Boys	202	48.5
Girls	215	51.5
Age group in years		
3.0 to <4.0	212	49.6
4.0 to <5.0	205	50.4
Weight status		
Underweight/wasting	5	1.2
Healthy weight	355	85.2

At risk of overweight	47	11.2
Overweight/obese	10	2.4
Education class [a]		
High	56	13.5
Low	358	85.8
Missing [b]	*3*	*0.7*
Residential setting		
Urban	100	24.1
Rural	317	75.9
Season of the year		
Cool dry	153	36.8
Hot wet	264	63.2
	Number	Mean (SE)
Mean age in years	417	4.0 (0.0)
Restrained sitting, min/day	414 [c]	19.8 (4.2)
Sedentary screen time, min/day	414 [c]	43.0 (7.1)
Sleep duration, h/day	414 [d]	11.2 (0.1)
Accelerometer TPA, steps/day	372 [d]	24,269 (391)
Accelerometer TPA, min/day	372 [d]	264.5 (6.0)

Notes: a denotes education class was parent reported; b denotes participants with accelerometry data only; c denotes participants with parent-reported movement behaviours (restrained sitting, sedentary screen time, and sleep duration; d denotes participants with accelerometry-measured physical activity data for ≥3 valid days; SE= standard error; min/day = minutes per day; h/day = hours per day; TPA = total physical activity.

Prevalence of Meeting Guidelines

Prevalence estimates of meeting the global 24-hour movement guidelines in Malawi are summarised in *Figure 5-6* and *Table 5-7*. Overall, most children met the TPA (98%; 95% CI: 96, 99%) and sleep duration (91%; 96% CI: 87, 93%) guidelines, over three-quarters met the restrained sitting (76%; 95% CI: 68, 83%) and sedentary screen time (79%; 95% CI: 71, 86%) guidelines, and 60% met all four of the guidelines (95% CI: 53, 67%).

Prevalence of meeting the restrained sitting guideline was higher among children from lower SES families and rural residents compared to their urban counterparts. In addition, a minority of children from higher SES and urban settings met the screen time guideline and all four movement guidelines compared to their rural counterparts.

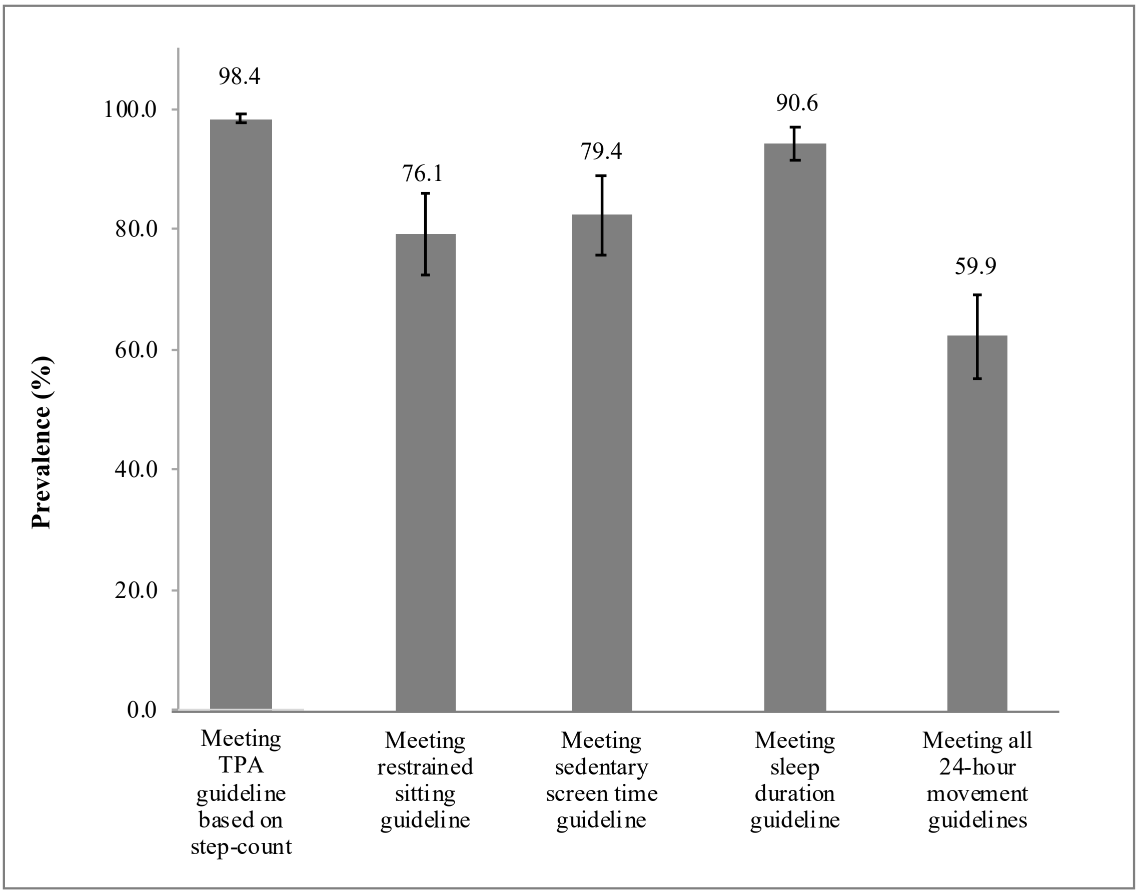

Figure 5-6: Prevalence of meeting the global 24-hour movement guidelines.

Notes: Each bar represents the prevalence estimate for meeting the global movement guidelines, and the vertical lines extending from each bar indicate the corresponding 95% confidence intervals. TPA = total physical activity; Meeting all 24-h movement guidelines was defined as parent-reported restrained sitting of no more than 1 hour at a time, ≤60 min/day for sedentary screen time, at least 10-13 hours/day for sleep duration, and ≥11,500 steps/day for TPA.

Table 5-7: Percentage of 3–4-year-old children in Malawi meeting the WHO 24-hour movement guidelines

	Number	Percent	95% CI
Meeting TPA guideline based on accerelometry step counts [a]			
Overall	366	98.4	96.0, 99.4
Sex			
Boys	173	97.7	94.1, 99.1
Girls	193	99.0	95.8, 99.8
Age group in years			
3.0 to <4.0	182	98.4	94.9, 99.5
4.0 to <5.0	184	98.4	94.8, 99.5

Weight status			
Underweight	4	100.0	-
Healthy weight	315	98.4	95.6, 99.5
At risk of overweight	39	97.5	82.4, 99.7
Overweight/obese	8	100.0	-
Education class			
High	42	100.0	-
Low	321	98.2	95.4, 99.3
Residential setting			
Urban	78	98.7	91.8, 99.8
Rural	288	98.3	95.2, 99.4
Season of the year			
Cool dry	133	99.2	94.7, 99.9
Hot wet	233	97.9	94.4, 99.3
Meeting restrained sitting guideline [b]			
All	315	76.1	68.1, 82.6
Sex			
Boys	152	75.9	65.4, 84.0
Girls	163	76.2	66.9, 83.5
Age group in years			
3.0 to <4.0	162	76.8	68.9, 83.2
4.0 to <5.0	153	75.4	64.0, 84.0
Weight status			
Underweight/ wasting	3	60.3	21.4, 87.9
Healthy weight	274	77.9	69.3, 84.7
At risk of overweight	32	67.3	49.8, 81.1
Overweight/obese	6	60.0	34.0, 81.3
Education class			
High	25	44.4***	27.8, 62.4
Low	290	81.1***	74.8, 86.1
Residential setting			
Urban	54	54.9**	33.3, 74.9
Rural	261	82.7**	76.2, 87.7
Season of the year			
Cool dry	119	78.6	61.9, 89.3
Hot wet	196	74.6	64.4, 82.6

Meeting sedentary screen time guideline [b]			
Overall	329	79.4	71.2, 85.7
Sex			
Boys	156	78.0	68.8, 85.1
Girls	173	80.7	72.0, 87.1
Age group in years			
3.0 to <4.0	173	82.0	72.9, 88.5
4.0 to <5.0	156	76.8	65.0, 85.6
Weight status			
Underweight	4	80.8**	40.5, 96.3
Healthy weight	284	80.6**	73.0, 86.4
At risk of overweight	37	78.7**	63.2, 88.9
Overweight/obese	4	38.6**	12.6, 73.3
Education class			
High	11	19.5***	10.4, 33.6
Low	318	88.8***	84.0, 92.4
Residential setting			
Urban	35	35.7***	18.3, 57.8
Rural	294	93.0***	89.2, 95.5
Season of the year			
Cool dry	110	72.8	57.7, 84.0
Hot wet	219	83.2	64.6, 93.1
Meeting sleep duration guideline [b]			
Overall	375	90.6	87.3, 93.2
Sex			
Boys	181	90.6	84.9, 94.2
Girls	194	90.7	86.8, 93.5
Age group in years			
3.0 to <4.0	188	89	84.0, 92.7
4.0 to <5.0	187	92.1	86.9, 95.4
Weight status			
Underweight	3	58.9	14.8, 92.2
Healthy weight	321	91.2	87.5, 93.9
At risk of overweight	41	87.4	72.5, 94.8
Overweight/obese	10	100.0	-
Education class			
High	45	80.5**	70.3, 87.8

Low	330	92.2**	89.0, 94.0
Residential setting			
Urban	87	88.9	80.9, 93.7
Rural	288	91.2	87.4, 93.9
Season of the year			
Cool dry	137	90.9	84.0, 95.1
Hot wet	238	90.5	86.4, 93.4
Meeting all 24-hour movement guidelines [c]			
Overall	221	59.9	52.7, 66.7
Sex			
Boys	105	60.0	51.2, 68.1
Girls	116	59.9	50.9, 68.2
Age group in years			
3.0 to <4.0	109	59.2	50.3, 67.6
4.0 to <5.0	112	60.5	50.0, 70.2
Weight status			
Underweight	1	25.2	2.7, 80.4
Healthy weight	196	61.8	54.6, 68.6
At risk of overweight	22	55.0	37.7, 71.1
Overweight/obese	2	24.8	5.0, 67.2
Education class			
High	4	9.5***	2.3, 31.8
Low	217	66.4***	59.9, 72.3
Residential setting			
Urban	18	23.3***	9.6, 46.6
Rural	203	69.6***	63.9, 74.7
Season of the year			
Cool dry	80	60.6	46.6, 73.1
Hot wet	141	59.5	48.4, 69.7

Notes: a denotes N=368; b denotes n=414; c denotes sub-population with data on both parent-reported and accelerometry-measured movement behaviours (TPA, restrained sitting, sedentary screen time, and sleep duration; N=369); * $p<0.05$; ** $p<0.01$; *** $p<0.001$; TPA = total physical activity; Meeting all 24-h movement guidelines was defined as parent-reported restrained sitting of no more than 1 hour at a time, ≤60 min/day for sedentary screen time, at least 10-13 hours/day for sleep duration, and ≥11,500 steps/day for TPA.

Correlates of Meeting Guidelines

Table 5-8 presents univariable correlates of meeting the guidelines among 3–4-year-olds Generally, SES and residential settings were significantly associated with meeting the individual and all four guidelines combined. None of the potential correlates were associated with meeting the TPA guideline in the univariable analyses.

Table 5-9 provides multivariable correlates of meeting the 24-hour movement guidelines. Only meeting the sedentary screen time guideline was considered for the multivariable analyses. Specifically, children from urban settings were less likely to meet the guideline than those from rural settings (OR: 0.04; 95% CI: 0.01, 0.11; p<0.001).

Table 5-8: Univariable correlates of meeting the WHO 24-hour movement guidelines among 3–4-year-olds in Malawi

	OR (95% CI)	p-value
Meeting TPA guideline based on accelerometry step counts [a]		
Sex (ref: boys)	2.26 (0.52, 9.77)	0.258
Age group in years (ref: 3.0 to <4.0)	1.01 (0.22, 4.54)	0.988
Weight status (ref: healthy weight)		
At risk of overweight	0.61 (0.05, 7.14)	0.638
Overweight/obese	-	
Education class (ref: low)	-	n.a.
Residential setting (ref: rural)	1.34 (0.15, 11.94)	0.784
Season of the year (ref: Cool dry)	0.35 (0.04, 3.17)	0.336
Meeting restrained sitting guideline [b]		
Sex (ref: boys)	1.02 (0.59, 1.76)	0.952
Age group in years (ref: 3.0 to <4.0)	0.93 (0.54, 1.58)	0.766
Weight status (ref: healthy weight)		0.170
At risk of overweight	0.59 (0.30, 1.19)	
Overweight/obese	0.43 (0.12, 1.59)	
Education class (ref: low)	0.19 (0.09, 0.41)	**<0.001**
Residential setting (ref: rural)	0.26 (0.10, 0.68)	**0.008**
Season of the year (ref: Cool dry)	0.80 (0.29, 2.21)	0.648
Meeting sedentary screen time guideline [b]		
Sex (ref: boys)	1.18 (0.82, 1.70)	0.357
Age group in years (ref: 3.0 to <4.0)	0.73 (0.37, 1.43)	0.341
Weight status (ref: healthy weight)		**0.031**

At risk of overweight	0.89 (0.49, 1.62)	
Overweight/obese	0.15 (0.04, 0.58)	
Education class (ref: low)	0.03 (0.01, 0.08)	**<0.001**
Residential setting (ref: rural)	0.04 (0.01, 0.12)	**<0.001**
Season of the year (ref: Cool dry)	1.85 (0.44, 7.72)	0.381
Meeting sleep duration guideline [b]		
Sex (ref: boys)	1.02 (0.54, 1.91)	0.957
Age group in years (ref: 3.0 to <4.0)	1.43 (0.68,2.99)	0.325
Weight status (ref: healthy weight)		
At risk of overweight	0.71 (0.24, 2.11)	0.518
Overweight/obese	-	
Education class (ref: low)	0.35 (0.18, 0.69)	**0.004**
Residential setting (ref: rural)	0.77 (0.37, 1.63)	0.478
Season of the year (ref: Cool dry)	0.94 (0.44, 2.02)	0.874
Meeting all 24-hour movement guidelines [c]		
Sex (ref: boys)	1.00 (0.65, 1.51)	0.984
Age group in years (ref: 3.0 to <4.0)	1.06 (0.62, 1.80)	0.835
Weight status (ref: healthy weight)		0.159
At risk of overweight	0.77 (0.38, 1.55)	
Overweight/obese	0.21 (0.03, 1.25)	
Education class (ref: low)	0.05 (0.01, 0.27)	**0.001**
Residential setting (ref: rural)	0.13 (0.5, 0.39)	**0.001**
Season of the year (ref: Cool dry)	0.95 (0.41, 2.20)	0.907

Note: OR = odds ratio; CI = confidence interval; a denotes N=372; b denotes N=414; c denotes sub-analysis with data on both parent-reported and accelerometry-measured movement behaviours (TPA, restrained sitting, sedentary screen time, and sleep duration; N=369); TPA = total physical activity; Meeting the 24-h movement guidelines was defined as parent-reported restrained sitting of no more than 1 hour at a time, ≤60 min/day for sedentary time, at least 10-13 hours/day for sleep duration, and ≥11,500 steps/day for TPA.

Table 5-9: Multivariable correlates of meeting the WHO 24-hour movement guidelines among 3–4-year-olds in Malawi

	OR (95% CI)	P-value
Meeting sedentary screen time guideline [a]		
Weight status (ref: healthy weight)		0.474
At risk of overweight	1.50 (0.67, 3.37)	
Overweight/obese	0.67 (0.24, 1.89)	
Residential setting (ref: rural)	0.04 (0.02, 0.11)	**<0.001**

Notes: a denotes N=414; OR = odds ratio; CI = confidence interval.

Discussion

Key Findings

In the present study TPA based on accelerometry step count was exceptionally high, a high percentage of children met the individual guidelines (TPA, restrained sitting, sedentary screen time, and sleep duration) and a majority met all four guidelines combined. Children were also more physically active in the rural setting compared to the urban setting. Thus, the present study suggests that young children in Malawi may not yet have experienced the physical activity transition, though young children in urban areas may be in transition.[19]

Comparisons with the Literature

Only one study in Europe previously used daily step-counts to define TPA when examining the prevalence and correlates of meeting the TPA guideline in young children.[57] The recent data-pooling study by Chong et al.[14] from 3-4 year olds in 33 globally diverse countries (but with substantial under-representation of children from low-income countries) used ActiGraph accelerometry-measured time spent in TPA and MVPA to operationalise adherence to the physical activity guideline, used the SUNRISE Study parent/caregiver questionnaires (as in the present study) to measure adherence to the sedentary screen time and sleep duration guidelines, but did not report adherence to the restrained sitting guideline. Methodological differences between the present study and the global data pooling study make direct comparisons of the percentage of samples meeting guidelines problematic because of the different methods used for assessing physical activity. For example, in the present study TPA was measured and adherence to the physical activity guideline defined using an average daily step count of ≥11,500. In contrast, the global pooling study used accelerometer-derived minutes of TPA and MVPA. Furthermore, the inclusion of the restrained sitting guideline in the present study further limits comparison with the global data pooling study. While real differences in the behaviours between populations are likely, comparisons between studies are not straightforward.[14]

The most direct comparison possible between the present study and the global data pooling study by Chong et al.[14] requires use of the ActiGraph movement data (rather than step count data) from the present study –operationalised as meeting both the TPA and MVPA guidelines for children to meet the combined physical activity guideline– and the same SUNRISE parent questionnaires in both the present and global data pooling study for screen time and sleep duration. The global data produced an estimate of only 14% of the sample meeting all three guidelines[14] while for the present study the prevalence estimate using the same three guidelines and the same measurement methods was 60%. Present study data therefore suggest a much higher prevalence of meeting the three guidelines than is typical globally, though with a substantial minority of children not meeting all three guidelines even in the present study. The recent study from Ethiopia of Abdeta et al.[15] used the SUNRISE Study protocol[24] but operationalised sleep duration using ActiGraph accelerometry and did not report adherence to the restrained sitting guideline, so the prevalence estimate from Ethiopia is not readily comparable with the present study. However, it is clear that, as in the present study, levels of TPA were very high in the Ethiopian 3-4 year olds studied by Abdeta et al.[15]

Prevalence of meeting the combined guidelines in the present study appears higher than that reported in SUNRISE Study pilot studies from two middle-income Sub-Saharan African countries, South Africa and Zimbabwe.[58,59] However, methodological differences in physical activity measurement limit direct comparison to the present study, as the two pilot studies used ActiGraph and activPAL measurement of TPA and MVPA. Previous studies in middle- and high-income countries reported prevalence of meeting all 24-hour movement guidelines ranging from 3% to 24%, but used a wide variety of methods, did not all include adherence to the same number of WHO guidelines, did not all include adherence to four guidelines (adherence to the restrained sitting guideline is often not measured or not reported), and did not all restrict their inclusion criteria to 3-4 year olds (in many studies older children were included so long as they had not yet started school and so in many cases were age 5 or 6 years).[58–72] Feng et al.[73] reviewed studies from 11 countries recently (including one middle-income country, South Africa) and found an average of 14% prevalence of meeting three of the four movement guidelines (for physical activity, sedentary screen time, sleep duration; all measured subjectively or objectively) among 3-4 year olds. Another recent systematic review and meta-analysis of studies of three of the four guidelines (physical activity, sedentary screen time, sleep duration; excluding restrained sitting) from 23 mostly high-income countries found that 11% of 3-4 year-olds met all guidelines combined.[74] In summary, while a number of studies of prevalence of meeting movement guidelines in young children are broadly similar to the present study, marked differences– in study design, size and purpose (pilot studies vs studies large enough for prevalence estimation), sampling, methods and numbers of guidelines considered – make comparisons of prevalence between studies difficult.

In the present study we identified few correlates of meeting the guidelines. Residential setting (urban/rural) was associated with meeting all four 24-hour movement guidelines as well as individual restrained sitting and sedentary screen time guidelines. This finding is consistent with an urban-rural comparison in older children and adolescents in Mozambique.[52] Consistent with findings in young children from some but not all studies in other income levels,[70,71] we did not find any sex differences in meeting individual and all four guidelines combined. Additionally, we did not identify any correlates of meeting the TPA guideline based on step-count. Since almost all of the children in the present study met the TPA guideline (98% met the TPA guideline using the step count threshold; 91% met the TPA guideline using accelerometry for movement sensing; Supplementary File 1 presented in *Appendix M* of this thesis), and levels of TPA were so high (averaging >24,000 steps/day, more than double the step count threshold equivalent to meeting the TPA guideline; 6.2 hours per day using accelerometry; Supplementary File 1 presented in *Appendix M* of this thesis) there was a ceiling effect making it difficult to identify correlates of meeting the TPA guideline. As noted above, the lack of comparability between studies of young children makes comparisons of the correlates of the movement behaviours between the present study and those other studies challenging, made even more challenging because different correlates have been considered by different studies and by the dearth of studies of correlates from LMICs.[31] However, the most highly relevant comparison is with the recent study by Abdeta et al. from Ethiopia.[15] Abdeta et al.[15] considered three potential correlates (sex, urban vs rural residence, parental educational attainment) of meeting the physical activity (TPA and MVPA) /sedentary screen time /sleep duration guideline in 430 3-4 year olds and found that only urban-rural residence was a significant correlate, with higher prevalence of meeting the screen time guideline in children from rural than urban areas, consistent with the present study.

Implications of the Present Study

The physical activity transition was underway across many parts of Africa as long ago as the early 2000s.[75] The present study suggests that rural populations in Malawi have not yet experienced the physical activity transition. Identifying populations before they experience the physical activity transition might provide an opportunity for low-income countries to preserve their current high levels of physical activity to enhance public health and reduce the burden of movement behaviour and obesity-related NCDs while undergoing economic development. Intervention development to preserve physical activity of young children during economic development/urbanisation will be needed to minimise future NCD burden in Malawi and other countries which have not yet undergone the physical activity transition.

Malawi currently has a national physical activity surveillance system for adults[10,76] but not children, and so in the absence of studies like the present there would be negligible evidence on the physical activity transition[19] in children. The present study will provide baseline data for planning future surveillance and research during the country's economic transformation.[18] In addition, findings of the present study are consistent with the Behavioural Epidemiology Framework[27] by providing critical evidence required to determine the levels of meeting all global 24-hour movement guidelines and identify high risk population groups to develop targeted public policies and interventions.

The national government in Malawi has a vision for transformational societal change, leading to an upper-middle- income, industrialised/more urbanised economy by 2063,[18] while addressing the major health challenges including NCDs.[76] Such a transformation will be challenging for NCD prevention as moving to a higher income/more urbanised economy is likely to promote physical activity transition.[19,75] At present Malawi has not adopted the WHO 2019 Movement Guidelines, has no guidelines or policy on movement behaviours in the under-5s, and no movement behaviour surveillance for children of any age.[6] Defending healthy levels of movement behaviours and physically active early lives (TPA in the present study was accumulated largely during many hours of outdoor play) during economic transformation and urbanisation will require that Malawi has policy, policy implementation, and surveillance to inform that policy and policy implementation all aimed at preserving high levels of physical activity during economic development and urbanisation.[21]

Strengths and Limitations

Our study has the important strength of novelty; evidence on levels and correlates of meeting movement guidelines from low-income countries is scarce.[24,31,74] There may be other potential correlates not included in the present study that might have substantial influence on movement behaviours of young children, though reviews of correlates of physical activity and sedentary behaviour in early childhood, which found evidence almost entirely from high-income countries, found few consistent correlates not included in the present study other than child motor skills and parental rules on screen time (the latter largely irrelevant at present for rural Malawi).[31,43] Future research should use a wider range of correlates drawn from the Socio-Ecological Model,[41] including individual- and environmental-level correlates. In the present study, large macro-environmental differences existed between urban and rural areas– electrical power sources (and therefore screens) were almost entirely unavailable to the rural children but widely available to the urban children for example.

Parent reports of time spent in movement behaviours of their children may be subject to substantial measurement error, arising from issues such as social desirability bias.[77] There are few evidence syntheses of validation studies of parent reported movement behaviours in 3-4 year olds. A recent systematic review of sleep time measurement in the under 5s found that none of the published methods had been demonstrated to have adequate reliability and validity.[78] The SUNRISE Study parent report of child sleep (timing, quality, and duration) has recently been validated against accelerometry, with good validity and reliability globally,[79] increasing confidence in the sleep duration estimates from the present study and suggesting no need to correct for measurement error. In our previous study we found that parent reported TPA using the SUNRISE Study questionnaire was invalid when compared against accelerometry, but step-counting was an accurate and practical objective alternative[33] and so could be used with confidence in subsequent studies in LMICs including the present study. Estimates of time spent in restrained sitting and sedentary screen time are difficult to validate given the practical problem of measuring screen time and time restrained in young children, and the absence of an established screen time reference method.[80] The development of a globally appropriate screen time measurement method was one of the highest priorities reported in a recent Delphi Study of movement behaviour surveillance across childhood and adolescence.[21] In the absence of evidence about reliability and validity of the SUNRISE Study sedentary screen time questionnaire, it is not clear whether correction for measurement error is required. Differences in questionnaire administration between urban and rural families were unavoidable in the present study and it is not clear if these would have had any impact on the questionnaire data obtained. Parental education was used as proxy for family SES,[47] yet other measures such as household income may provide valid estimate of household's SES. However, income may not provide reliable estimates due to reliance on the informal economy in many LMICs.[48]

Our sample was not nationally representative; however, analyses used post-stratification survey weights based on national proportions from census data[49] to provide representative estimates. Our previous study with a global sample of 3-4 year olds found that the 11,500/day step count threshold had excellent sensitivity (100%) and specificity (89%) for classification of meeting or not meeting the WHO guideline for TPA[33] and so that is suitable for the present study. We are not aware of any similar calibration studies which have assessed the ability of step counting to assess meeting the MVPA guideline in 3-4 year olds, and so we were limited to measuring TPA in the present study. Finally, the use of post-hoc power calculations is a limitation but we did not depend solely on those, provided confidence intervals around our prevalence estimates, and exceeded the minimum number of participants per potential correlate suggested by correlate study guidance.

Conclusions

We found exceptionally high physical activity and prevalence of meeting the four individual and combined movement guidelines, with significantly higher odds of meeting all four movement behaviour guidelines among rural than urban children. These findings indicate that Malawi's population has not yet experienced the physical activity transition.[19] This presents a valuable opportunity for Malawi and other countries in similar contexts to learn from middle- and high-income countries that have already experienced the transition and develop policy interventions to preserve these healthy levels of movement behaviours as economic developments progress.

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Authors' contributions

TM-V, XJ, and JJR contributed to the data acquisition, conceptualisation, data analysis and interpretation, drafting, review, and final approval of the manuscript. ADO, JJK, KHC, PC, and SE contributed to data acquisition as well as reviewed and approved the manuscript.

Declaration of interest

The authors declare that they have no competing interests.

Data Sharing Statement

Anonymised data from the present study will be made available for sharing from the University of Strathclyde, via the corresponding author, from January 2027.

Submitted manuscript references

1. World Health Organization. *World Health Organisation Guidelines for Physical Activity, Sedentary Behaviour, and Sleep for Children under 5 Years of Age*.; 2019. Accessed March 13, 2024. https://www.who.int/publications/i/item/9789241550536

2. Dumuid D, Olds T, Sawyer SM. Moving beyond more: towards a healthy balance of daily behaviours. *The Lancet*. 2021;398(10298):373-374. doi:10.1016/S0140-6736(21)01600-7

3. Chaput JP, Gray CE, Poitras VJ, et al. Systematic review of the relationships between sleep duration and health indicators in the early years (0-4 years). *BMC Public Health*. 2017;17. doi:10.1186/s12889-017-4850-2

4. Rollo S, Antsygina O, Tremblay MS. The whole day matters: Understanding 24-hour movement guideline adherence and relationships with health indicators across the lifespan. *J Sport Health Sci*. 2020;9(6):493-510. doi:10.1016/j.jshs.2020.07.004

5. Janssen X, Martin A, Hughes AR, Hill CM, Kotronoulas G, Hesketh KR. Associations of screen time, sedentary time and physical activity with sleep in under 5s: A systematic review and meta-analysis. *Sleep Med Rev*. 2020;49.

6. Carson V, Lee EY, Hewitt L, et al. Systematic review of the relationships between physical activity and health indicators in the early years (0-4 years). *BMC Public Health*. 2017;17(Suppl 5). doi:10.1186/s12889-017-4860-0

7. Jones RA, Hinkley T, Okely AD, Salmon J. Tracking physical activity and sedentary behavior in childhood: A systematic review. *Am J Prev Med*. 2013;44(6):651-658. doi:10.1016/j.amepre.2013.03.001

8. Wadsworth MEJ, Kuh DJL. Childhood influences on adult health: A review of recent work from the British 1946 national birth cohort study, the MRC National Survey of Health and Development. *Paediatr Perinat Epidemiol*. 1997;11(1):2-20. doi:10.1046/j.1365-3016.1997.d01-7.x

9. World Health Organization. *Global Action Plan on Physical Activity 2018–2030: More Active People for a Healthier World*.; 2018. https://www.who.int/publications/i/item/9789241514187

10. World Health Organization. *Global Status Report on Physical Activity 2022: Country Profiles*.; 2022. https://www.who.int/teams/health-promotion/physical-activity/global-status-report-on-physical-activity-2022

11. Aubert S, Brazo-Sayavera J, González SA, et al. Global prevalence of physical activity for children and adolescents; inconsistencies, research gaps, and recommendations: a narrative review. *International Journal of Behavioral Nutrition and Physical Activity*. 2021;18(1):1-11. doi:10.1186/s12966-021-01155-2

12. De Craemer M, Veldman SLC, Azevedo LB, et al. Practical steps needed to achieve impact of the WHO 2019 movement behaviour guidelines for children under the age of 5: the SUNRISE Study Europe Group evaluation. *The Lancet Regional Health - Europe*. 2024;39:100869. doi:10.1016/j.lanepe.2024.100869

13. Nusurupia J, J. RJ, Xanne J. Pre-school children's compliance with the WHO 24-hour movement behaviour guidelines: a systematic review of Sub-Saharan African studies. *African Journal for Physical Activity and Health Sciences (AJPHES)*. 2020;26(4):345-359. doi:10.10520/ejc-ajpherd1-v26-n4-a2

14. Chong KH, Suesse T, Cross PL, et al. Pooled Analysis of Physical Activity, Sedentary Behavior, and Sleep Among Children From 33 Countries. *JAMA Pediatr*. 2024;178(11):1199. doi:10.1001/jamapediatrics.2024.3330

15. Abdeta C, Cliff D, Kariippanon K, et al. Adherence to the WHO physical activity, screen time and sleep guidelines and associations with socio-demographic factors among Ethiopian preschool children: The SUNRISE study. *Journal of Activity, Sedentary and Sleep Behaviors*. 2024;3(1):22. doi:10.1186/s44167-024-00060-w

16. Malawi Communications Regulatory Authority, National Statistical Office. *National Survey on Access and Use of Information and Communication Technologies by Households and Individuals in Malawi 2023*.; 2023. Accessed December 4, 2024. https://macra.mw/research/

17. Government of Malawi. *The Fifth Integrated Household Survey (IHS5) 2020 Report*.; 2020. Accessed June 26, 2024. https://microdata.worldbank.org/index.php/catalog/3818

18. Government of Malawi. *Malawi's Vision: An Inclusively Wealthy and Self-Reliant Nation*.; 2020. Accessed March 3, 2024. https://npc.mw/wp-content/uploads/2021/02/MW2063-VISION-FINAL.pdf

19. Katzmarzyk PT, Mason C. The Physical Activity Transition. *J Phys Act Health*. 2009;6(3):269-280. doi:10.1123/jpah.6.3.269

20. Reilly JJ, Aubert S, Brazo-Sayavera J, Liu Y, Cagas JY, Tremblay MS. Surveillance to improve physical activity of children and adolescents. *Bull World Health Organ*. 2022;100(12):815-824. doi:10.2471/BLT.22.288569

21. Reilly JJ, Andrew R, Abdeta C, et al. Improving National and International Surveillance of Movement Behaviours in Childhood and Adolescence: An International Modified Delphi Study. *Sports Medicine*. Published online October 3, 2024. doi:10.1007/s40279-024-02104-2

22. UNICEF, African Union. *Children in Africa: Key Statistics on Child Survival and Population*.; 2017. Accessed December 15, 2024. https://data.unicef.org/wp-content/uploads/2019/01/Children-in-Africa.pdf

23. Arts J, Gubbels JS, Verhoeff AP, Chinapaw MJM, Lettink A, Altenburg TM. A systematic review of proxy-report questionnaires assessing physical activity, sedentary behavior and/or sleep in young children (aged 0–5 years). *International Journal of Behavioral Nutrition and Physical Activity*. 2022;19(1):1-40. doi:10.1186/s12966-022-01251-x

24. Okely AD, Reilly JJ, Tremblay MS, et al. Cross-sectional examination of 24-hour movement behaviours among 3- and 4-year-old children in urban and rural settings in low-income, middle-income and high-income countries: the SUNRISE study protocol. *BMJ Open*. 2021;11(10):e049267. doi:10.1136/bmjopen-2021-049267

25. Ding D, Carson V, Hunter RF, et al. Science has no Borders, so Should Scientific Publishing: A Position Statement from the Journal of Physical Activity and Health. *J Phys Act Health*. 2022;19(12):809-810. doi:10.1123/jpah.2022-0570

26. Carson V, Draper CE, Okely A, Reilly JJ, Tremblay MS. Future Directions for Movement Behavior Research in the Early Years. *J Phys Act Health*. 2024;21(3):218-221. doi:10.1123/jpah.2023-0679

27. Sallis JF, Owen N, Fotheringham MJ. Behavioral epidemiology: A systematic framework to classify phases of research on health promotion and disease prevention. *Annals of Behavioral Medicine*. 2000;22(4):294-298. doi:10.1007/BF02895665

28. Chaput JP, Carson V, Gray CE, Tremblay MS. Importance of all movement behaviors in a 24 hour period for overall health. *Int J Environ Res Public Health*. 2014;11(12):12575-12581. doi:10.3390/ijerph111212575

29. Domingues-Montanari S. Clinical and psychological effects of excessive screen time on children. *J Paediatr Child Health*. 2017;53(4):333-338. doi:10.1111/jpc.13462

30. Okely A, Tremblay M, Reilly J, Draper C, Bull F. Physical activity, sedentary behaviour, and sleep: movement behaviours in early life. *Lancet Child Adolesc Health*. 2018;2:233-235.

31. Arts J, Drotos E, Singh AS, Chinapaw MJM, Altenburg TM, Gubbels JS. Correlates of Physical Activity in 0- to 5-year-olds: A Systematic Umbrella Review and Consultation of International Researchers. *Sports Medicine*. 2023;53(1):215-240. doi:10.1007/s40279-022-01761-5

32. Aubert S, Barnes JD, Demchenko I, et al. Global Matrix 4.0 Physical Activity Report Card Grades for Children and Adolescents: Results and Analyses From 57 Countries. *J Phys Act Health*. 2022;19(11):700-728. doi:10.1123/jpah.2022-0456

33. Mwase-Vuma TW, Janssen X, Okely AD, et al. Validity of low-cost measures for global surveillance of physical activity in pre-school children: The SUNRISE validation study. *J Sci Med Sport*. 2022;25(12):1002-1007. doi:10.1016/j.jsams.2022.10.003

34. Government of Malawi. *The Second Malawi Multidimensional Poverty Index Report*.; 2022. Accessed June 26, 2024. https://www.undp.org/malawi/publications/second-malawi-multidimensional-poverty-index

35. Harris PA, Taylor R, Thielke R, Payne J, Gonzalez N, Conde JG. Research electronic data capture (REDCap)-A metadata-driven methodology and workflow process for providing translational research informatics support. *J Biomed Inform*. 2009;42(2):377-381. doi:10.1016/j.jbi.2008.08.010

36. De Craemer M, De Decker E, Santos-Lozano A, et al. Validity of the Omron pedometer and the actigraph step count function in preschoolers. *J Sci Med Sport*. 2015;18(3):289-293. doi:10.1016/j.jsams.2014.06.001

37. Mwase-Vuma TW, Janssen X, Chong KH, et al. Prevalence and Correlates of Adherence to the Global Total Physical Activity Guideline Based on Step Counting Among 3- to 4-Year-Olds: Evidence From SUNRISE Pilot Studies From 17 Countries. *J Phys Act Health*. 2024;21(8):794-801. doi:10.1123/jpah.2023-0711

38. Bassett DR, Toth LP, LaMunion SR, Crouter SE. Step Counting: A Review of Measurement Considerations and Health-Related Applications. *Sports Medicine*. 2017;47(7):1303-1315. doi:10.1007/s40279-016-0663-1

39. Guseh JS, Figueroa JF. Evaluating the Health Benefits of Low-Frequency Step-Based Physical Activity-The “Weekend Warrior” Pattern Revisited. *JAMA Netw Open*. 2023;6(3):e235184. doi:10.1001/jamanetworkopen.2023.5184

40. De Craemer M, De Decker E, De Bourdeaudhuij I, Verloigne M, Manios Y, Cardon G. The translation of preschoolers’ physical activity guidelines into a daily step count target. *J Sports Sci*. 2015;33(10):1051-1057. doi:10.1080/02640414.2014.981850

41. Sallis JF, Owen N, Fisher EB. Ecological models of health behaviour. In: Glanz K, Rimer BK, Viswanath K., eds. *Health Behavior and Health Education: Theory, Research, and Practice*. 4th ed. ; 2008:465-485.

42. Hinkley T, Salmon J, Okely AD, Trost SG. Correlates of sedentary behaviours in preschool children: a review. *International Journal of Behavioral Nutrition and Physical Activity*. 2010;7(1):66. doi:10.1186/1479-5868-7-66

43. Dias KI, White J, Jago R, et al. International comparison of the levels and potential correlates of objectively measured sedentary time and physical activity among three-to-four-year-old children. *Int J Environ Res Public Health*. 2019;16(11). doi:10.3390/ijerph16111929

44. World Health Organization. The STEPS Instrument. *Noncommunicable Disease Surveillance, Monitoring and Reporting*.

45. Leroy JL. zscore06: Stata command for the calculation of anthropometric z-scores using the 2006 WHO child growth standards. Published online 2011.

46. De Onis M, Lobstein T. Defining obesity risk status in the general childhood population: Which cut-offs should we use? *International Journal of Pediatric Obesity*. 2010;5(6):458-460. doi:10.3109/17477161003615583

47. Vanderauwera J, van Setten ERH, Maurits NM, Maassen BAM. The interplay of socio-economic status represented by paternal educational level, white matter structure and reading. *PLoS One*. 2019;14(5):e0215560. doi:10.1371/JOURNAL.PONE.0215560

48. Howe LD, Galobardes B, Matijasevich A, et al. Measuring socio-economic position for epidemiological studies in low-and middle-income countries: A methods of measurement in epidemiology paper. *Int J Epidemiol*. 2012;41(3):871-886. doi:10.1093/ije/dys037

49. National Statistical Office. *2018 Malawi Population and Housing Census Report*.; 2019. Accessed June 26, 2024. https://malawi.unfpa.org/en/publications/malawi-2018-population-and-housing-census-main-report

50. World Bank Group. Malawi Climate Data: Historical. Climate Change Knowledge Portal. Accessed June 12, 2024. https://climateknowledgeportal.worldbank.org/country/malawi/climate-data-historical

51. Cliff DP, Reilly JJ, Okely AD. Methodological considerations in using accelerometers to assess habitual physical activity in children aged 0-5 years. *J Sci Med Sport*. 2009;12(5):557-567. doi:10.1016/j.jsams.2008.10.008

52. Manyanga T, Barnes JD, Chaput JP, Katzmarzyk PT, Prista A, Tremblay MS. Prevalence and correlates of adherence to movement guidelines among urban and rural children in Mozambique: A cross-sectional study. *International Journal of Behavioral Nutrition and Physical Activity*. 2019;16(1):1-12. doi:10.1186/s12966-019-0861-y

53. Dormann CF, Elith J, Bacher S, et al. Collinearity: A review of methods to deal with it and a simulation study evaluating their performance. *Ecography*. 2013;36(1):27-46. doi:10.1111/j.1600-0587.2012.07348.x

54. O'Brien RM. A caution regarding rules of thumb for variance inflation factors. *Qual Quant*. 2007;41(5):673-690. doi:10.1007/s11135-006-9018-6

55. Uijtdewilligen L, Nauta J, Singh AS, et al. Determinants of physical activity and sedentary behaviour in young people: a review and quality synthesis of prospective studies. *Br J Sports Med*. 2011;45:896–905. doi:10.1136/bjsports-2011-090197

56. Vandenbroucke JP, Von Elm E, Altman DG, et al. Strengthening the Reporting of Observational Studies in Epidemiology (STROBE): Explanation and Elaboration. *PLoS Medicine | www*. 2007;4. doi:10.1371/journal.pmed

57. De Craemer M, Verbestel V, Cardon G, Androutsos O, Manios Y, Chastin S. Correlates of meeting the physical activity, sedentary behavior, and sleep guidelines for the early years among belgian preschool children: The ToyBox-study. *Int J Environ Res Public Health*. 2020;17(19):1-15. doi:10.3390/ijerph17197006

58. Munambah N, Gretschel P, Muchirahondo F, et al. 24 hour movement behaviours and the health and development of pre-school children from Zimbabwean settings: The SUNRISE pilot study. *South African Journal of Sports Medicine*. 2021;33(1):1-9. doi:10.17159/2078-516X/2021/v33i1a10864

59. Draper C, Tomaz S, Cook C, et al. Understanding the influence of 24-hour movement behaviours on the health and development of preschool children from low-income South African settings: the SUNRISE pilot study. *South African Journal of Sports Medicine*. 2020;32:1-7. doi:10.17159/2078-516X/2020/v32i1a8415

60. Leppänen MH, Ray C, Wennman H, et al. Compliance with the 24-h movement guidelines and the relationship with anthropometry in Finnish preschoolers: The DAGIS study. *BMC Public Health*. 2019;19(1):1-8. doi:10.1186/s12889-019-7967-7

61. De Craemer M, McGregor D, Androutsos O, Manios Y, Cardon G. Compliance with 24-h movement behaviour guidelines among belgian pre-school children: The toybox-study. *Int J Environ Res Public Health*. 2018;15(10):1-10. doi:10.3390/ijerph15102171

62. Ramírez-Vélez R, Izquierdo M, López-Gil JF, et al. Prevalence of meeting all three 24-h movement guidelines and its correlates among preschool-aged children. *Scand J Med Sci Sports*. 2023;33(6):979-988. doi:10.1111/sms.14320

63. Feng J, Huang WY, Reilly JJ, Wong SHS. Compliance with the WHO 24-h movement guidelines and associations with body weight status among preschool children in Hong Kong. *Applied Physiology, Nutrition and Metabolism*. 2021;46(10):1273-1278. doi:10.1139/apnm-2020-1035

64. Goncalves WSF, Byrne R, de Lira PIC, Viana MT, Trost SG. Adherence to 24-hour movement guidelines among rural Brazalian preschool children: associations with parenting practices. *International Journal of Behavioral Nutrition and Physical Activity*. 2022;19(1). doi:10.1186/s12966-022-01369-y

65. Guan H, Zhang Z, Wang B, et al. Proportion of kindergarten children meeting the WHO guidelines on physical activity, sedentary behaviour and sleep and associations with adiposity in urban Beijing. *BMC Pediatr*. 2020;20(1):1-9. doi:10.1186/s12887-020-1969-6

66. Hinkley T, Timperio A, Watson A, et al. Prospective associations with physiological, psychosocial and educational outcomes of meeting Australian 24-hour movement guidelines for the early years. *International Journal of Behavioral Nutrition and Physical Activity*. 2020;17(1). doi:10.1186/s12966-020-00935-6

67. Hossain MS, Deeba IM, Hasan M, et al. International study of 24-h movement behaviors of early years (SUNRISE): a pilot study from Bangladesh. *Pilot Feasibility Stud*. 2021;7(1):1-9. doi:10.1186/s40814-021-00912-1

68. Kim H, Ma J, Harada K, Lee S, Gu Y. Associations between adherence to combinations of 24-h movement guidelines and overweight and obesity in Japanese preschool children. *Int J Environ Res Public Health*. 2020;17(24):1-11. doi:10.3390/ijerph17249320

69. Lee ST, Wong JE, Chan GKL, Poh BK. Association between compliance with movement behavior guidelines and obesity among malaysian preschoolers. *Int J Environ Res Public Health*. 2021;18(9). doi:10.3390/ijerph18094611

70. Kracht CL, Webster EK, Staiano AE. Sociodemographic Differences in Young Children Meeting 24-Hour Movement Guidelines. *J Phys Act Health*. 2019;16(10):908-915. doi:10.1123/jpah.2019-0018

71. Vale S, Mota J. Adherence to 24-hour movement guidelines among Portuguese preschool children: the prestyle study. *J Sports Sci*. 2020;38(18):2149-2154. doi:10.1080/02640414.2020.1775385

72. Byambaa A, Dechinjamts O, Jambaldorj B, Jones RA, Chong KH, Okely AD. Prevalence and Health Associations of Meeting the World Health Organization Guidelines for Physical Activity, Sedentary Behavior, and Sleep in Preschool-Aged Children: The SUNRISE Mongolia Pilot and Feasibility Study. *J Phys Act Health*. 2024;21(3):283-293. doi:10.1123/jpah.2023-0511

73. Feng J, Zheng C, Sit CHP, Reilly JJ, Huang WY. Associations between meeting 24-hour movement guidelines and health in the early years: A systematic review and meta-analysis. *J Sports Sci*. 2021;39(22):2545-2557. doi:10.1080/02640414.2021.1945183

74. Tapia-Serrano MA, Sevil-Serrano J, Sánchez-Miguel PA, López-Gil JF, Tremblay MS, García-Hermoso A. Prevalence of meeting 24-hour movement guidelines from pre-school to adolescence: A systematic review and meta-analysis including 387,437 participants and 23 countries. *J Sport Health Sci*. 2022;11(4):427-437. doi:10.1016/j.jshs.2022.01.005

75. Muthuri SK, Wachira LJM, Leblanc AG, et al. Temporal trends and correlates of physical activity, sedentary behaviour, and physical fitness among school-aged children in Sub-Saharan Africa: A systematic review. *Int J Environ Res Public Health*. 2014;11(3):3327-3359. doi:10.3390/ijerph110303327

76. Ministry of Health. *Malawi National STEPwise Survey for Non-Communicable Diseases Risk Factors*.; 2017. https://extranet.who.int/ncdsmicrodata/index.php/catalog/629/download/5770

77. Shephard RJ. Limits to the measurement of habitual physical activity by questionnaires. *Br J Sports Med*. 2003;37:197-206. doi:10.1136/bjsm.37.3.197

78. Antsygina O, Rollo S, McRae N, Chaput JP, Tremblay MS. Reliability and validity of instruments containing reported sleep measures among children from birth to <5 years of age: A systematic review. *Sleep Med Rev*. 2025;79. doi:10.1016/j.smrv.2024.102023

79. Zhang Z, Abdeta C, Chelly MS, et al. Psychometric properties of SUNRISE Study Parent Questionnaire for assessing pre- schooler sleep and sleep-related family practices. *Sleep Health: Journal of the National Sleep Foundation*. 2025. Under Review.

80. Downing KL, Janssen X, Reilly JJ. Feasibility of wearable cameras to assess screen time and time spent restrained in children aged 3 to 5 years: A study protocol. *BMJ Open*. 2019;9(5). doi:10.1136/bmjopen-2018-028265

5.4 Preface references

1. Reilly JJ, Aubert S, Brazo-Sayavera J, Liu Y, Cagas JY, Tremblay MS. Surveillance to improve physical activity of children and adolescents. *Bull World Health Organ*. 2022;100(12):815-824. doi:10.2471/BLT.22.288569

2. Carson V, Draper CE, Okely A, Reilly JJ, Tremblay MS. Future Directions for Movement Behavior Research in the Early Years. *J Phys Act Health*. 2024;21(3):218-221. doi:10.1123/jpah.2023-0679

3. Arts J, Drotos E, Singh AS, Chinapaw MJM, Altenburg TM, Gubbels JS. Correlates of Physical Activity in 0- to 5-year-olds: A Systematic Umbrella Review and Consultation of International Researchers. *Sports Medicine*. 2023;53(1):215-240. doi:10.1007/s40279-022-01761-5

4. Tapia-Serrano MA, Sevil-Serrano J, Sánchez-Miguel PA, López-Gil JF, Tremblay MS, García-Hermoso A. Prevalence of meeting 24-hour movement guidelines from pre-school to adolescence: A systematic review and meta-analysis including 387,437 participants and 23 countries. *J Sport Health Sci*. 2022;11(4):427-437. doi:10.1016/j.jshs.2022.01.005

5. Okely AD, Reilly JJ, Tremblay MS, et al. Cross-sectional examination of 24-hour movement behaviours among 3- and 4-year-old children in urban and rural settings in low-income, middle-income and high-income countries: the SUNRISE study protocol. *BMJ Open*. 2021;11(10):e049267. doi:10.1136/bmjopen-2021-049267

6. Nusurupia J, J. RJ, Xanne J. Pre-school children's compliance with the WHO 24-hour movement behaviour guidelines: a systematic review of Sub-Saharan African studies. *African Journal for Physical Activity and Health Sciences (AJPHES)*. 2020;26(4):345-359. doi:10.10520/ejc-ajpherd1-v26-n4-a2

7. Chong KH, Suesse T, Cross PL, et al. Pooled Analysis of Physical Activity, Sedentary Behavior, and Sleep Among Children From 33 Countries. *JAMA Pediatr*. 2024;178(11):1199. doi:10.1001/jamapediatrics.2024.3330

8. Abdeta C, Cliff D, Kariippanon K, et al. Adherence to the WHO physical activity, screen time and sleep guidelines and associations with socio-demographic factors among Ethiopian preschool children: The SUNRISE study. *Journal of Activity, Sedentary and Sleep Behaviors*. 2024;3(1):22. doi:10.1186/s44167-024-00060-w

9. National Statistical Office. *2018 Malawi Population and Housing Census Report*.; 2019. Accessed June 26, 2024. https://malawi.unfpa.org/en/publications/malawi-2018-population-and-housing-census-main-report

10. UN Habitat. Malawi. Accessed January 30, 2025. https://unhabitat.org/malawi

11. The World Bank. Malawi GDP per capita. 2023. Accessed March 3, 2025. https://data.worldbank.org/indicator/NY.GDP.PCAP.CD?locations=MW

12. The World Bank. World Bank country and lending groups. Accessed December 12, 2024. https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups

13. Government of Malawi. *The Second Malawi Multidimensional Poverty Index Report*.; 2022. Accessed June 26, 2024. https://www.undp.org/malawi/publications/second-malawi-multidimensional-poverty-index

14. National Statistical Office. *Malawi Multiple Indicator Cluster Survey 2019-20, Survey Findings Report.*; 2021. Accessed July 22, 2023. https://www.nsomalawi.mw/publications/health/multiple-indicator-cluster-survey-2019-20

15. Government of Malawi. *The Fifth Integrated Household Survey (IHS5) 2020 Report*.; 2020. Accessed June 26, 2024. https://microdata.worldbank.org/index.php/catalog/3818

16. National Statistical Office, ICF. *2024 Malawi Demographic and Health Survey - Key Indicators Report*.; 2025. Accessed March 10, 2025. https://www.nsomalawi.mw/publications/demography/malawi-demographic-and-health-survey-2024-key-indicators-report

17. World Health Organization. *Country Disease Outlook: Malawi*.; 2023. https://www.afro.who.int/sites/default/files/2023-08/Malawi.pdf

18. Malawi Communications Regulatory Authority, National Statistical Office. *National Survey on Access and Use of Information and Communication Technologies by Households and Individuals in Malawi 2023*.; 2023. Accessed December 4, 2024. https://macra.mw/research/

19. National Statistical Office. *Malawi: Beyond Connections - Energy Access Diagnostic Report Based on Multi-Tier Framework*.; 2024. Accessed March 20, 2025. https://www.energy.gov.mw/1008-2/

20. Naing L, Winn T, Rusli BN. Practical Issues in Calculating the Sample Size for Prevalence Studies. *Archives of Orofacial Sciences*. 2006;1:9-14. https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.504.2129&rep=rep1&type=pdf

21. Draper C, Tomaz S, Cook C, et al. Understanding the influence of 24-hour movement behaviours on the health and development of preschool children from low-income South African settings: the SUNRISE pilot study. *South African Journal of Sports Medicine*. 2020;32:1-7. doi:10.17159/2078-516X/2020/v32i1a8415

22. Harris PA, Taylor R, Thielke R, Payne J, Gonzalez N, Conde JG. Research electronic data capture (REDCap)-A metadata-driven methodology and workflow process for providing translational research informatics support. *J Biomed Inform*. 2009;42(2):377-381. doi:10.1016/j.jbi.2008.08.010

23. Kang H. The prevention and handling of the missing data. *Korean J Anesthesiol*. 2013;64(5):402-406. doi:10.4097/kjae.2013.64.5.402

24. Austin PC, White IR, Lee DS, van Buuren S. Missing Data in Clinical Research: A Tutorial on Multiple Imputation. *Canadian Journal of Cardiology*. 2021;37(9):1322-1331. doi:10.1016/j.cjca.2020.11.010

25. Sallis JF, Owen N, Fotheringham MJ. Behavioral epidemiology: A systematic framework to classify phases of research on health promotion and disease prevention. *Annals of Behavioral Medicine*. 2000;22(4):294-298. doi:10.1007/BF02895665

26. Katzmarzyk PT, Mason C. The Physical Activity Transition. *J Phys Act Health*. 2009;6(3):269-280. doi:10.1123/jpah.6.3.269

Chapter 6: General Discussion

6.1 Introduction

The main purposes of this thesis were to (1) establish the cultural appropriateness and accuracy of low-cost measurement methods for assessing the global total physical activity guideline in 3–4 year olds and (2) determine the prevalence and identify correlates of meeting the global 24-hour movement guidelines among Malawian 3–4 year-olds. This body of work was developed through two distinct phases: The first phase was through secondary analyses of pooled anonymised data from the first two pilot phases of the SUNRISE International Study (Chapters 3 and 4).[1] The second phase was through primary data collection that involved 3- and 4-year olds recruited from urban and rural ECEC centres in Malawi (Chapter 5). To address the main purposes of this thesis, five specific objectives were developed across three thesis studies, as outlined in Chapter 1 (*Section 1.2*) and highlighted below.

Chapter 3 (Study 1)	1. To validate low-cost measures for assessing habitual TPA in 3–4 year olds from 13 culturally and geographically diverse countries.
Chapter 4 (Study 2)	2. To examine the prevalence of meeting the global TPA guideline based on daily step-counts in 3–4 year olds from 17 middle- and high-income countries.
	3. To examine the sociodemographic correlates of meeting the TPA guideline based on daily step-counts in 3–4 year olds from 17 middle- and high-income countries.
Chapter 5 (Study 3)	4. To examine the prevalence of meeting the global 24-hour movement behaviour guidelines in Malawian 3–4 year-olds.
	5. To examine the sociodemographic correlates of meeting the global 24-hour movement behaviour guidelines in Malawian 3–4 year-olds.

These objectives were addressed in three distinct studies as noted above. Therefore, this chapter provides a summary and interpretation of key findings from the three thesis studies. Due to the lack of comparable literature from low-income SSA contexts, comparisons with previous studies will primarily focus on evidence from systematic reviews and global pooled analysis studies, as appropriate.

6.2 Key findings and contribution to knowledge

6.2.1 Thesis study 1

Study 1 addressed Research Question 1, which was aimed at validating low-cost measures (parent-reports and step counts) for assessing habitual TPA against accelerometry data among

3–4 year olds from vastly diverse backgrounds globally. This study was a secondary analysis of pilot data from 13 culturally and geographically diverse countries globally that participated in phases 1 and 2 of the SUNRISE International Study.[1] A sample of 351 children was included in this analysis. The findings were published in the *Journal of Science and Medicine in Sports* and have been reported in Chapter 3 of this thesis (Mwase-Vuma T, Janssen X, […] Reilly J. JSAMS. 2022).

The findings showed that parents could not accurately report the time their child spent in habitual TPA. This finding is consistent with a 2021 systematic review that found that proxy reported measurement tools lacked validity for determining physical activity in children aged 3–7 years.[2] Similarly, a 2022 systematic review found that all the identified questionnaires for assessing physical activity in children aged 2–6 years were insufficiently valid and reliable for assessment of physical activity in children aged 3–6 years.[3] It should be noted that both systematic reviews were based on limited evidence – the studies included in the 2021[2] and 2022[3] systematic reviews were of low/very low-quality, with the 2021 review particularly including very few studies.[2]

Furthermore, our findings showed that step-counting with a threshold of 11,500 steps/day appears to provide an accurate, relatively simple, and low-cost alternative (e.g., using pedometers costing as little as $26 USD) to parent-reports for assessing compliance with the global TPA guideline in young children globally, including in LMICs. The study is in line with Phase 2 of the Behavioural Epidemiology Framework,[4] which requires establishing the validity of measurement methods in early stages of research. The study also contributes to the body of knowledge given the lack of consensus with the existing step-count thresholds for classifying meeting the global TPA guideline.[5–7] Additionally, the study supports the urgent need for accurate, simpler, and inexpensive measurement methods (e.g., step-counting using pedometers) to promote equity in physical activity research[8] and improve population health globally.[9] Thus, step-counting with a threshold of at least 11,500 steps/day could potentially be used for physical activity surveillance in young children in Malawi and other similar settings to minimise the cost and complexity of other measurement methods based on activity duration and intensity.

6.2.2 Thesis study 2

Study 2 used evidence from Study 1 to address Research Question 2, which was to examine the levels and sociodemographic correlates of compliance with the global TPA guideline based on a daily step count threshold of 11,500 steps among 3–4 year-olds globally. The study used secondary data from 797 pre-school children aged 3–4 years from 17 culturally and geographically varied countries that participated in phases 1 and 2 of the SUNRISE International Study.[1] The sample comprised children from lower- and upper-MICs and HICs globally. The findings were published in the *Journal of Physical Activity and Health* and have been reported in Chapter 4 of this thesis (Mwase-Vuma T, Janssen X, […] Reilly J. JPAH. 2024).

Results from this study showed that compliance with the global TPA guideline among 3–4 year-olds globally is low (31%). This finding is lower than the mean prevalence (67%) of meeting the global TPA guideline reported in a 2021 systematic review and meta-analysis.[10] Similarly, a 2023 systematic review and meta-analysis reported that 78% of 3–4 year olds met the global TPA guideline based on accelerometry-measured activity duration data.[11] A possible explanation for the discrepancy could be methodological differences as some of the studies (i.e., 8 out of 18) included in the 2021 systematic review and meta-analysis involved infants and toddlers (0-2 years) and 5-year olds.[10] Some studies also included in the 2021 systematic review assessed physical activity using proxy reports,[10] which may not be sufficiently valid,[2,3] as confirmed by the findings presented in Chapter 3 of this thesis. Another possible explanation is that none of the studies included in both reviews[10,11] assessed compliance of meeting the TPA guidelines using step counting. In addition, our study focused specifically on TPA using step counts, while the review by Feng et al.[10] included both TPA and MVPA components in the assessment of meeting the global physical activity guideline, using different measurement approaches that may partly explain the differing prevalence estimates.

In addition, sociodemographic correlates of compliance with the global TPA guideline were identified, and the results showed that boys, older children, and those from rural settings and MICs were more likely to meet the guideline. The finding from this study (Chapter 4) suggests that interventions to improve physical activity in young children should consider the various sociodemographic differences to enhance their impact. Additionally, the study supports the need to conduct (more) movement behaviour research in LMIC to allow comparison of the prevalence estimates across country income groups,[12] including low-, middle-, and high-income, while also acknowledging the heterogeneity within these broad classifications. In line with the Behavioural Epidemiology Framework,[4] this would provide a deeper understanding of the correlates of the 24-hour movement behaviours in young children from these diverse contexts and inform tailored interventions to address the needs of each income group.

6.2.3 Thesis study 3

This study addressed Research Question 3 of this thesis, and involved a cross-sectional primary data collection in a low-income SSA context to examine the prevalence and determine the sociodemographic correlates of compliance with the global 24-hour movement guidelines among Malawian 3–4 year olds, which is consistent with Phase 3 and 4 of the Behavioural Epidemiology Framework.[4,12] The study comprised a sample of 417 children aged 3–4 years recruited from urban and rural ECEC centre in Malawi. The findings were reported in Chapter 5 of this thesis (Mwase-Vuma T, Janssen X, […] Reilly J. 2024).

The findings showed relatively high level of compliance with all four 24-hour movement guidelines among Malawian 3–4 year old children. As earlier noted, there was almost no evidence on the prevalence of compliance with the global 24-hour movement guidelines in young children from SSA at the time the research work in this thesis started in 2021. Until recently, only two studies examined the prevalence of meeting the global guidelines in young children from low-income SSA settings.[13,14] Using a pooled sample of 3–4 year olds from 33 countries, including Malawi (n=54), Chong et al.[14] found very low prevalence (14%) of meeting the three 24-hour movement guidelines (physical activity measured via accelerometry, screen time and sleep duration assessed by parent report), with prevalence estimates ranging from 14% in HIC to 17% in low-/lower-middle-income countries (Malawi 44%). The discrepancy could be due to methodological differences, including children from LICs being substantially under-represented in the Chong et al.[14] study.

Furthermore, our study showed relatively high prevalence (60%) of meeting all four 24-hour movement guidelines (TPA, restrained sitting, screen time, and sleep duration), which is similar to the Ethiopian study[13] that found that 58% of 3–4 year olds met three global guidelines (physical activity, screen time, and sleep duration). It is worth noting that the two previous studies[13,14] defined meeting the physical activity guideline as meeting both TPA and MVPA guidelines and did not assess the restrained sitting guideline. It is therefore important to bear in mind the number of guidelines assessed (three versus four) when comparing our findings across apparently similar studies.

Our study is also consistent with the Ethiopian study[13] that found that meeting the three global 24-hour movement guidelines (physical activity [including TPA and MVPA], screen time, and sleep duration) was influenced by residential setting, with rural children more likely to meet the guidelines than their urban counterparts. However, another study that included 3–4 year olds from 10 LMICs, including two SSA countries (i.e., South Africa and Zimbabwe) did not find any differences in meeting all four 24-hour movement guidelines between urban and rural settings.[15] The discrepancy could be due to methodological differences, as all countries included in the Nusurupia et al.[15] study are classified as MICs by the World Bank.[16] Another Ethiopian study[17] published in February 2025 near the completion period of writing this thesis provides complementary insights by examining correlates of time 3–4 year olds spent in the individual 24-hour movement behaviours (physical activity [including TPA and MVPA], sedentary behaviours, screen time, and sleep). While comparison with the present study is not possible due to the different outcome measures, Abdeta et al.[17] found that child's sex, parental education, and residence (urban versus rural) influenced the time children spent in the 24-hour movement behaviours. These findings offer additional context of children's activity patterns in low-income SSA settings.

Nevertheless, the findings from the earlier Ethiopian study[13] and the present study are consistent with the physical activity transition theory,[18] suggesting that the Malawian population is in the pre-physical transition period. Like in many other SSA countries,[19] most people in Malawi live in rural areas (84%) where there is poor quality road infrastructure and network, with most short journeys being made on foot, and generally most people have limited access to electricity and electronic devices as earlier noted.[20–22] Such rural environments offer greater opportunities of physically active lifestyles which delay the transition. However, the country's envisioned economic transformation by 2063[23] may result in rapid urbanisation and associated physical activity transition.[18] Indeed, our findings, which revealed that a minority of urban children are meeting the sedentary screen time (36% versus 93% in rural areas) and all four guidelines (23% versus 70% in rural areas) combined, suggest that a screen time transition, which often precedes the broader physical activity transition,[18] may already be underway in Malawian urban areas.

6.3 Implications for policy and practice

Given the importance of 24-hour movement behaviours in early childhood and evidence suggesting that many African countries had already started experiencing the physical activity transition,[18,24] this research has important implications for policy and practice. First, this research provides evidence on the validity of a simple, relatively cheaper, and culturally appropriate measurement method based on step-counting that could be used to inform national surveillance systems and population-based surveys to monitor trends in compliance with the global guidelines, which are currently lacking in Malawi and many other low-income countries globally.[25,26] Such measurement methods are needed in large-scale and surveillance studies to minimise costs, generate valid data that can be used to compare countries and country-income groups,[12] and ensure consistent and sustained national surveillance system in young children to inform policies and interventions to increase physical activity and reduce sedentary lifestyles.[25] Besides, step-based recommendations can easily be measured and understood by the general population,[9,27] thus potentially being useful in Malawi and similar settings to promote physically active behaviours.

The shift from accelerometry-derived intensity measures to step counting represents a potentially more accessible and pragmatic approach for measuring physical activity that may help enhance equity in movement behaviour research and improve public health globally.[8,9] Step-based goals have gained considerable attention in the global literature. For example, recent publications, including an editorial[28] and commentary,[9] have emphasised that step counting may provide more democratised access to physical activity compared to complex accelerometry-derived intensity measures. While intensity-based guidelines remain important, Tudor-Locke et al.'s cadence work demonstrates that steps per minute can provide proxy measures for intensity,[29] which may vary across populations and age groups, so further work is necessary to identify how best to use cadence as a good proxy for intensity in different populations.

Nevertheless, step counting offers a practical balance between measurement validity and implementation feasibility in resource-limited settings, potentially enabling broader global participation in movement behaviour research.

Additionally, it is worth noting that the step counts used for assessing total physical activity were derived from accelerometers (i.e., *activ*PAL™ in Chapters 3 and 4, and ActiGraph in Chapter 5) which are both expensive and require complex data processing. As previously mentioned, the use of these devices may not be financially sustainable for establishing national surveillance systems in LMICs.[30] This is because these countries face significant health challenges due to a double burden of communicable and non-communicable diseases, and their limited financial resources are often disproportionately prioritised for tackling communicable diseases.[31] In other words, LMICs may have limited financial capacity to establish national surveillance systems that use accelerometry-derived measures of physical activity. Therefore, these countries could establish surveillance systems using simpler and less expensive devices, such as pedometers, which demonstrate high correlations with step counts derived from accelerometers in young children.[32]

It is also worth noting that establishing movement behaviour surveillance systems in young children using simpler and less expensive devices for step counts and parent reports for restrained sitting, sedentary screen time, and sleep duration has the potential to be financially sustainable in resource-limited settings, like Malawi. Given the limited evidence and the lack of national surveillance systems in LMICs,[26,33,34] that have been previously noted, this approach is particularly important for establishing broad baseline evidence rather than pursuing detailed intensity data. However, establishing such systems would still require considerable financial investments for purchasing pedometers, building local capacity for data interpretation, and establishing systems for ongoing technical support. These investments would require sustained funding[25] in order to monitor the levels of compliance with the global 24-hour movement behaviour guidelines[35] and track progress towards achieving the 2030 global physical activity target.[25]

Furthermore, this research has provided baseline data that can be used for tracking levels of compliance with the global 24-hour movement guidelines during Malawi's economic transformation,[23] as well as for comparing these compliance levels with those of other countries in similar settings in SSA and globally. The research also provides evidence to inform the development of policies and interventions to promote healthy movement behaviours and sustain the high levels of compliance with the global guidelines in Malawi and other low-income contexts. This will in turn contribute to reducing the burden of movement behaviours and obesity related NCDs.

Our finding of the influence of residential settings in meeting the global 24-hour movement behaviour guidelines, both at the global and local level, is an important finding of this thesis. Rural children were more likely to meet the TPA and all four guidelines compared to their urban counterparts, indicating that urbanicity has a significant impact on unfavourable health outcomes such as low physical activity and overweight/obesity.[36] The high level of meeting all 24-hour movement behaviour guidelines compared to other populations internationally, with relatively higher levels among rural than urban children, suggests a population in the pre-physical activity transition period.[18]

The physical activity transition[18] has enormous implications for public health in LMICs, as it may lead to health risks associated with sedentary lifestyles, such as NCDs.[37] This is particularly concerning in these pre-physical activity transition societies like Malawi as they are already burdened with communicable diseases.[37,38] This resulting dual burden of diseases in LMICs may put significant pressure on the country's limited health system and household-level financial resources.[39]

While evidence suggests that many countries in Africa have already experienced or are experiencing the physical activity transition,[24] the research findings from this thesis suggest that the transition only appears to be underway in the urban settings. This provides an opportunity for Malawi and other LICs to learn from HICs that have already experienced the transition in order to develop tailored interventions to promote healthy movement behaviours and sustain high compliance levels during the economic transition. These interventions could include urban-based school and community programmes that encourage children and families to be more physically active and less engaged in sedentary behaviours. By fostering environments that prioritise healthy movement behaviours, Malawi and other LICs can mitigate the risk of movement behaviour- and obesity-related NCDs that often accompany socioeconomic transition and urbanisation.

Furthermore, the research findings on the correlates of meeting the guidelines could be used to inform targeted interventions for promoting healthy movement behaviours among children. This information could also be incorporated into the health and education policy documents, such as the Malawian Early Childhood Development (ECD) curriculum and training profession development of ECEC educators to support and promote 24-hour movement behaviour guidelines at ECEC settings. The educators could use this knowledge to advocate for the global 24-hour movement guidelines and communicate with parents/caregivers to support their children’s compliance with the guidelines at home, e.g., by promoting physical activity, managing their electronic device use, and encouraging appropriate sleep duration and habits. Additionally, given the importance of ECEC settings on the health and educational outcomes in young children,[40] these settings provide a unique opportunity for promoting healthy movement behaviours in this age group, particularly in LMICs. Thus, the ECD curriculum in these settings can be adapted to include structured activities that promote active play, daytime naps, and reduce sedentary behaviours among children.

Finally, the importance of promoting 24-hour movement behaviours in the early years to sustain the high levels of compliance with the global guidelines could also be communicated to community health workers (CHW). In Malawi, CHWs are the largest cadre of healthcare workers primarily responsible for providing primary level of care at the community level, including promotive, preventive, and basic curative healthcare services.[41] CHWs provide a link between communities and the country's formal health system, and their services have historically contributed to improved health outcomes among children and women.[42] These CHWs conduct health promotional activities at community group meetings, health facilities (e.g., at hospitals, health centres, and clinics), and door-to-door.[42] Therefore, health promotional activities could be adapted to include advocacy efforts to encourage families promote healthy movement behaviours in young children, such as accessing parks and playgrounds, to help children be physically active, limiting their use of electronic screen devices, and encouraging bedtime routines necessary for children's optimal growth and development.

6.4 Strengths and limitations

Specific strengths and limitations for each study in this thesis have been discussed in respective chapters (i.e., Chapters 3, 4, and 5). This section therefore focuses on discussing the overall strengths and limitations of the research in this thesis to avoid repetition.

The body of research in this thesis has a number of strengths. First, novelty–this thesis research presents the first large study on compliance with the global 24-hour movement behaviours in Malawi and one of the few studies targeting 3–4 year olds from a low-income SSA context. This is also one of the few studies presenting evidence based on a global sample of children from vastly diverse countries, including LMICs, that are currently underrepresented in the global literature.[12,33,34,43] The methods and approaches used across the three studies in this thesis followed rigorous and best practices to allow practical learning for practitioners and other researchers, as well as to enable replication within future research. In particular, research in this thesis established that the step count threshold of 11,500 steps/day equivalent to 180 minutes per day of TPA is a valid, practical, and culturally appropriate option for assessing compliance with the global TPA guideline and could potentially be used in surveillance studies in LMICs as noted above.

Furthermore, this thesis made use of the SUNRISE International Study protocol,[1] which allowed standardised data collection and will enable comparisons of our findings with LICs in SSA settings and other income groups globally. Data collection tools (e.g., parent questionnaire) were translated into the local language that was used for primary data collection in Malawi to ensure questions were applicable to the local context (as described in Chapter 5). Another strength is obtaining funding from the Canadian Institutes for Health Research (CIHR) to expand research in this thesis by implementing a larger study with a sample of 1000 children (i.e., the SUNRISE International Main Study) recruited across all three regions of Malawi. This larger national study will help examine the cultural influence in meeting the global movement behaviour guidelines among 3–4 year olds in the country.

In addition, additional funding was obtained from the University of Strathclyde/ISPF/SFC grant to expand on the dissemination and impact activities of the research in this thesis (particularly Chapter 5). Specifically, the findings presented in Chapter 5 were disseminated at five workshops with various stakeholders at the local (community), regional, and national levels in Malawi. Regional and national stakeholders also contributed to co-creation of future research for this doctoral project (see Future Research Directions section of this thesis for details). Target impact beneficiaries included families, local practitioners in education and health, national policymakers in education, health and social welfare, non-governmental organisations, and academia (a full report of the dissemination and impact activities is provided in *Appendix B* of this thesis). Thus, the success of this project was built upon many factors, including the support and collaboration of the SUNRISE researchers globally and the Coordinating Centre team at the University of Wollongong, various funding sources, and the research team in Malawi. This collaborative approach not only enriched the research process in this thesis but also ensured that the findings and future research plans are relevant to the local context.

Finally, a considerable strength of this work is that it has significantly contributed to capacity building in 24-hour movement behaviour research and surveillance among 3–4 year olds in Malawi (e.g., three research staff were trained in assessment method for the work presented in this thesis and an additional four staff were trained for the CIHR-funded project; the PhD student [author] has gained expertise in assessment methods, data processing and analysis, and interpretation). The research capacity building is one of the key priorities for improving national and international surveillance of movement behaviours among children and adolescents globally,[44] including in LMICs.[25] As such, the capacity built from this work can be used to support future research and surveillance initiatives in Malawi and other LMIC settings.

Despite the significant contribution in the field of 24-hour movement behaviours in the early years in LMICs, the body of research in this thesis may be limited in several ways. First, each of the studies was based on cross-sectional data, which have limited ability to determine the direction of the association between meeting the global 24-hour movement guidelines and the identified sociodemographic correlates (discussed in Chapters 4 and 5). For example, the relationship between weight status and movement behaviours could be bi-directional, as excess weight might lead to reduced physical activity, and low physical activity could contribute to weight gain.

Another limitation is the potentially limited generalisability of the research findings. Samples were not nationally representative, particularly for thesis study 3 (Chapter 5) which focused on children recruited from one district in southern Malawi. Additionally, the use of electronic devices for assessing physical activity among young children was relatively new in Malawi. Initial community concerns about the devices, including unfounded associations with witchcraft, required careful engagement with the ECEC centre directors and staff and parents to address potential barriers to participation.

The choice of step count measures over activity intensity counts enhanced the cultural appropriateness of the method used for assessing compliance with the global 24-hour movement behaviour guidelines rather than the electronic devices themselves (e.g., ActiGraph). Unlike activity intensity measures, step counts provide more accessible and interpretable results, as they may be more easily understood by the public,[27] including parents, educators, and policymakers. Therefore, step counts have greater practical utility within the Malawian context by facilitating better translation of findings into practice. This was particularly important given the low literacy levels[20] and resource and capacity gaps in movement behaviour research that may limit the ability to understand and translate intensity-based measures.

The success of the cultural appropriateness of the adapted SUNRISE protocol[1] in Malawi is reflected in the study outcome. Overall, participation rates remained acceptable (82%) and were comparable to other SUNRISE studies globally (e.g., 89% in Bangladesh,[45] 89% in Ethiopia,[13] 90% in Mongolia,[46] and 91% in Vietnam[47]). The participation rate demonstrates the successful cultural appropriateness of the SUNRISE International Study protocol.[1] Nevertheless, caution should be taken when generalising the findings to other regions in Malawi and similar contexts. Future research in similar settings should consider systematic assessment of cultural appropriateness, including the use of qualitative methods to evaluate the acceptability of the electronic devices for assessing physical activity within the target population.

Furthermore, our primary analysis of meeting the physical activity guideline focused on TPA using step count equivalent to 180 minutes/day of TPA.[5] This is because there is currently no established step count threshold equivalent to 60 minutes/day of MVPA that has been validated in a diverse sample of 3–4 year olds globally. We acknowledge a study from nearly two decades ago that proposed a threshold of 13,874 steps/day as equivalent to 60 minutes of MVPA in Belgian preschoolers aged 4.0–4.5 years.[48] However, we could not confidently use this threshold in this thesis because it was based on a smaller sample size (n=76) and due to the lack of validation evidence from culturally diverse samples of young children globally, including those from resource limited settings like SSA. Besides, Chapter 5 findings revealed that Malawian children accumulated an average of over 24,000 steps/day, which means the majority achieved the proposed daily step count threshold equivalence for MVPA. Nevertheless, we conducted additional analysis of meeting the global TPA guideline based on accelerometry-based activity duration and intensity (i.e., minutes/day) as per the WHO recommendations.[35] This supplementary analysis, which included both TPA and MVPA activity duration guidelines (see *Appendix L*), showed exceptionally high levels of compliance (92%), similar to the finding based on the daily step count threshold of 11,500 steps (98%).

Finally, the research presented in this thesis may be limited due to the varying reliability and validity of the methods used for assessing the different movement behaviours. Accelerometry-based activity counts and step counting provide reasonably valid measures for assessing physical activity[2] despite their outstanding methodological limitations for use in population-level surveillance studies.[49] Evidence presented in Chapter 5 relied on proxy parent reports for assessing compliance with the remaining three global guidelines (restrained sitting, sedentary screen time, and sleep duration), which may have limited established validity[2] and may also be subjected to recall difficulties and social desirability bias.[3,50] A 2022 systematic review[3] found that none of the assessed proxy-report questionnaires had reasonable validity for assessing movement behaviours (physical activity, sedentary behaviours, and sleep) in young children, partly due to poor quality evidence. However, there are currently no better available alternative methods for assessing these behaviours in large-scale global studies. As earlier noted, the 2022 systematic review[3] findings were based on low/very low-quality evidence. Besides, the SUNRISE parent questionnaire used in this research for assessing sleep (timing, quality, and duration) provides reasonably valid and reliable measures among 3–4 year olds globally (Under Review).[51] Nevertheless, caution should be exercised when interpreting our findings based on proxy parent reports (i.e., restrained sitting, sedentary screen time, and sleep duration).

6.5 Future research directions

6.5.1 Proposed next steps for this project

The proposed next step for this project follows the phases of the Behavioural Epidemiology Framework[18] to translate research evidence into practice. This would involve implementing interventions to promote physical activities and reduce sedentary behaviour (e.g., screen time) among young children in urban settings. However, such interventions would best be implemented after addressing the lack of a nationally representative sample outlined in the limitations section of this thesis above. Thus, studies using a larger and nationally representative sample in Malawi would be crucial to better understand the 24-hour movement behaviours across diverse cultural backgrounds in Malawi (i.e., predominantly Tumbukas in the north, Chewas in the centre, and Lhomwes and Yaos in the south), as well as to ascertain the levels of compliance with the global guidelines.

At the time this thesis was being written, the SUNRISE Main Study with a larger sample of 1000 children was being implemented in Malawi with funding from the CIHR (PhD student [author] local PI; 2022-25). The work is undertaken to expand the body of work in this thesis to all three regions of Malawi in order to reflect the diverse cultural backgrounds in these regions. This larger study aims to provide a comprehensive understanding of the 24-hour movement behaviours and levels and correlates of compliance with the global guidelines among 3–4 year olds across the varied cultural contexts in the country. The findings from this larger study will also help to inform targeted interventions and policies tailored to the specific needs of each cultural group across the three regions of Malawi.

As earlier mentioned, funding was obtained in 2024 from the University of Strathclyde/ ISPF/ SFC grant to expand on dissemination and impact activities of research in this thesis (particularly Chapter 5) at workshops with local, regional, and national level stakeholders in Malawi (a detailed report is provided in *Appendix B* of this thesis). One important outcome from the dissemination and impact activities was co-creation of future research with stakeholders, and an outline research proposal has been developed to inform future grant applications (as highlighted in *Appendix B*). The main future research plans include:

1. A longitudinal study to prospectively examine the changes in movement behaviours in childhood during the country's socioeconomic transition into an upper-MIC by 2063[23] and associated urbanisation. The design of this proposed study would ideally allow examining the direction of the association between meeting the global movement behaviour guidelines and a wider range of sociodemographic correlates drawn from the Social Ecological Model,[52] which is lacking in the body of work presented in this thesis.

2. Repeated cross-sectional studies to monitor the trends in healthy movement behaviours and understand how the country's urbanisation and economic transformation[23] would impact the levels of meeting the global 24-hour movement behaviour guidelines among Malawian children. This proposed study would ideally leverage the larger CIHR-funded cross-sectional study as the baseline data, with subsequent rounds conducted in five-year intervals, starting with 2029/30 after the baseline round.

6.5.2 Other research opportunities

This thesis presented evidence on 24-hour movement behaviours among young children from a low-income SSA context. Previous research in this area mainly focused on studies conducted in middle- and high-income countries, with very little evidence from LMICs in SSA contexts. Through undertaking this thesis, additional future research opportunities have been identified to advance the evidence on the 24-hour movement behaviours in the early years from LIC contexts, particularly in SSA. Further research may use the low-cost and culturally appropriate method validated in this thesis for assessing compliance with the TPA guideline based on step counting in young children as noted above.

In addition, research in this thesis was based on data from 3–4 year olds recruited from ECEC centres. The movement behaviours of these children may be different from those not attending

ECEC programmes. As a result, future studies should also include recruiting children not attending ECEC programmes, given that only 34% of eligible children (i.e., 3–4 year olds) attend formal ECEC programmes[53] and that early childhood education (ECE) is not mandatory in Malawi, but a national ECD strategy is available to promote ECE attendance.[54] Finally, research is required to validate step count threshold equivalent to 60 minutes/day of MVPA in young children from diverse backgrounds globally to provide a comprehensive understanding of childhood 24-hour movement behaviours based on simple, valid, and practical assessment methods.

6.6 Conclusions

Movement behaviours (physical activity, sedentary behaviour, and sleep) are important for children's healthy growth and development and have been identified as critical components for the prevention and control of NCD and related obesity. Urbanisation and socioeconomic transformations, particularly in LMICs, may negatively affect these behaviours and influence the physical activity transition and its associated health consequences, such as NCDs and related obesity. The WHO published the first global 24-hour movement behaviour guidelines for children under the age of five to promote optimum healthy growth and development in early childhood and as one way of tackling NCDs and the obesity pandemic globally. This thesis provides a unique contribution to the body of knowledge on 24-hour movement behaviours in the early years, particularly from LMICs. This thesis included the first large study in Malawi and one of the few large studies to target 3–4 year olds in a low-income SSA context and globally. This thesis research suggests that compliance with the global 24-hour movement guidelines is relatively high among Malawian 3–4 year olds, particularly in rural settings. Future studies examining behavioural changes and trends in compliance levels amidst Malawi's envisioned economic transformation are needed. A larger study is presently being completed in all three regions of Malawi, and the clear next steps for this research project are to conduct follow-up longitudinal and repeated cross-sectional studies. Findings from this thesis research and impact activities provide invaluable insights for informing: (1) national surveillance systems that use a valid, practical, and culturally appropriate measurement method for assessing TPA; (2) policy interventions to promote and sustain healthy movement behaviours in young children; and (3) future research directions relevant to the local context.

6.7 Chapter references

1. Okely AD, Reilly JJ, Tremblay MS, Kariippanon KE, Draper CE, El Hamdouchi A, et al. Cross-sectional examination of 24-hour movement behaviours among 3- and 4-year-old children in urban and rural settings in low-income, middle-income and high-income countries: the SUNRISE study protocol. BMJ Open [Internet]. 2021 Oct;11(10):e049267. Available from: https://bmjopen.bmj.com/lookup/doi/10.1136/bmjopen-2021-049267

2. Phillips SM, Summerbell C, Hobbs M, Hesketh KR, Saxena S, Muir C, et al. A systematic review of the validity, reliability, and feasibility of measurement tools used to assess the physical activity and sedentary behaviour of pre-school aged children. International Journal of Behavioral Nutrition and Physical Activity. 2021;18(1):1–28.

3. Arts J, Gubbels JS, Verhoeff AP, Chinapaw MJM, Lettink A, Altenburg TM. A systematic review of proxy-report questionnaires assessing physical activity, sedentary behavior and/or sleep in young children (aged 0–5 years). International Journal of Behavioral Nutrition and Physical Activity [Internet]. 2022;19(1):1–40. Available from: https://doi.org/10.1186/s12966-022-01251-x

4. Sallis JF, Owen N, Fotheringham MJ. Behavioral epidemiology: A systematic framework to classify phases of research on health promotion and disease prevention. Annals of Behavioral Medicine [Internet]. 2000;22(4):294–8. Available from: https://academic.oup.com/abm/article/22/4/294/4633687

5. De Craemer M, De Decker E, De Bourdeaudhuij I, Verloigne M, Manios Y, Cardon G. The translation of preschoolers' physical activity guidelines into a daily step count target. J Sports Sci [Internet]. 2015;33(10):1051–7. Available from: http://dx.doi.org/10.1080/02640414.2014.981850

6. Vale S, Trost SG, Duncan MJ, Mota J. Step based physical activity guidelines for preschool-aged children. Prev Med (Baltim) [Internet]. 2015;70:78–82. Available from: http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=emed13&NEWS=N&AN=25445332

7. Gabel L, Proudfoot NA, Obeid J, MacDonald MJ, Bray SR, Cairney J, et al. Step count targets corresponding to new physical activity guidelines for the early years. Med Sci Sports Exerc. 2013;45(2):314–8.

8. Ding D, Chastin S, Salvo D, Nau T, Gebel K, Sanchez-Lastra MA, et al. Realigning the physical activity research agenda for population health, equity, and wellbeing. The Lancet [Internet]. 2024;6736(24):4–6. Available from: https://linkinghub.elsevier.com/retrieve/pii/S014067362401540X

9. Guseh JS, Figueroa JF. Evaluating the Health Benefits of Low-Frequency Step-Based Physical Activity-The "Weekend Warrior" Pattern Revisited. JAMA Netw Open. 2023;6(3):e235184.

10. Feng J, Zheng C, Sit CHP, Reilly JJ, Huang WY. Associations between meeting 24-hour movement guidelines and health in the early years: A systematic review and meta-analysis. J Sports Sci [Internet]. 2021;39(22):2545–57. Available from: https://doi.org/10.1080/02640414.2021.1945183

11. Bourke M, Haddara A, Loh A, Carson V, Breau B, Tucker P. Adherence to the World Health Organization's physical activity recommendation in preschool-aged children: a systematic review and meta-analysis of accelerometer studies. International Journal of Behavioral Nutrition and Physical Activity 2023 20:1 [Internet]. 2023 Apr 26 [cited 2023 May 3];20(1):1–15. Available from: https://ijbnpa.biomedcentral.com/articles/10.1186/s12966-023-01450-0

12. Carson V, Draper CE, Okely A, Reilly JJ, Tremblay MS. Future Directions for Movement Behavior Research in the Early Years. J Phys Act Health [Internet]. 2024 Mar 1;21(3):218–21. Available from: https://journals.humankinetics.com/view/journals/jpah/21/3/article-p218.xml

13. Abdeta C, Cliff D, Kariippanon K, Deksisa A, Garoma S, Tesfaye D, et al. Adherence to the WHO physical activity, screen time and sleep guidelines and associations with socio-demographic factors among Ethiopian preschool children: The SUNRISE study. Journal of Activity, Sedentary and Sleep Behaviors [Internet]. 2024 Sep 11;3(1):22. Available from: https://jassb.biomedcentral.com/articles/10.1186/s44167-024-00060-w

14. Chong KH, Suesse T, Cross PL, Ryan ST, Aadland E, Aoko O, et al. Pooled Analysis of Physical Activity, Sedentary Behavior, and Sleep Among Children From 33 Countries. JAMA Pediatr [Internet]. 2024 Nov 1;178(11):1199. Available from: https://jamanetwork.com/journals/jamapediatrics/fullarticle/2824006

15. Nusurupia JJ, Germana LH, Wickramasinghe P, Tang HK, Munambah N, Hossain MS, et al. Urban Versus Rural Differences in Meeting 24-h Movement Behaviour Guidelines Among 3–4-Year-Olds: An Analysis of SUNRISE Pilot Study Data From 10 Low- and Middle-Income Countries. Child Care Health Dev. 2024 Nov 1;50(6).

16. The World Bank. World Bank country and lending groups [Internet]. [cited 2024 Dec 12]. Available from: https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups

17. Abdeta C, Cliff D, Kariippanon K, Deksisa A, Garoma S, Tesfaye D, et al. Child-, Family-, and Community-Level Correlates of 24-Hour Movement Behaviors in Ethiopian Young Children: The SUNRISE Study. J Phys Act Health [Internet]. 2025;1–10. Available from: https://journals.humankinetics.com/view/journals/jpah/aop/article-10.1123-jpah.2024-0556/article-10.1123-jpah.2024-0556.xml

18. Katzmarzyk PT, Mason C. The Physical Activity Transition. J Phys Act Health. 2009;6(3):269–80.

19. Jobarteh M. Sub-Saharan Africa: Geographic Futures [Internet]. 2025 [cited 2025 Jan 23]. Available from: https://futures.issafrica.org/geographic/regions/sub-saharan-africa/

20. Government of Malawi. The fifth integrated household survey (IHS5) 2020 report [Internet]. Zomba, Malawi; 2020 [cited 2024 Jun 26]. Available from: https://microdata.worldbank.org/index.php/catalog/3818

21. Malawi Communications Regulatory Authority, National Statistical Office. National Survey on Access and Use of Information and Communication Technologies by Households and Individuals in Malawi 2023 [Internet]. 2023 [cited 2024 Dec 4]. Available from: https://macra.mw/research/

22. National Statistical Office. Malawi: Beyond Connections - Energy Access Diagnostic Report Based on Multi-Tier Framework [Internet]. Zomba; 2024 [cited 2025 Mar 20]. Available from: https://www.energy.gov.mw/1008-2/

23. Government of Malawi. Malawi’s vision: An inclusively wealthy and self-reliant nation [Internet]. Lilongwe; 2020 [cited 2024 Mar 3]. Available from: https://npc.mw/wp-content/uploads/2021/02/MW2063-VISION-FINAL.pdf

24. Muthuri SK, Wachira LJM, Leblanc AG, Francis CE, Sampson M, Onywera VO, et al. Temporal trends and correlates of physical activity, sedentary behaviour, and physical fitness among school-aged children in Sub-Saharan Africa: A systematic review. Int J Environ Res Public Health. 2014;11(3):3327–59.

25. World Health Organization. Global status report on physical activity 2022 [Internet]. Geneva; 2022. Available from: https://www.who.int/teams/health-promotion/physical-activity/global-status-report-on-physical-activity-2022

26. World Health Organization. Global status report on physical activity 2022: Country profiles [Internet]. Geneva; 2022. Available from: https://www.who.int/teams/health-promotion/physical-activity/global-status-report-on-physical-activity-2022

27. Bassett DR, Toth LP, LaMunion SR, Crouter SE. Step Counting: A Review of Measurement Considerations and Health-Related Applications. Sports Medicine. 2017;47(7):1303–15.

28. Stamatakis E, Ahmadi M, Murphy MH, Chico TJ, Milton K, Cruz BDP, et al. Journey of a thousand miles: from 'Manpo-Kei' to the first steps-based physical activity recommendations. Br J Sports Med [Internet]. 2023 Oct 1;57(19):1227 LP – 1228. Available from: http://bjsm.bmj.com/content/57/19/1227.abstract

29. Tudor-Locke C, Craig CL, Beets MW, Belton S, Cardon GM, Duncan S, et al. How many steps/day are enough? For children and adolescents. International Journal of Behavioral Nutrition and Physical Activity. 2011;8:1–14.

30. Reilly J, Aubert S, Brazo-Sayavera J, Liu Y, Cagas J, Tremblay M. Surveillance to improve physical activity of children and adolescents. Bull World Health Organ [Internet]. 2022 Dec 1;100(12):815–24. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9706360/pdf/BLT.22.288569.pdf

31. Ganju A, Goulart AC, Ray A, Majumdar A, Jeffers BW, Llamosa G, et al. Systemic Solutions for Addressing Non-Communicable Diseases in Low- and Middle-Income Countries. J Multidiscip Healthc [Internet]. 2020 Jul;Volume 13:693–707. Available from: https://www.dovepress.com/systemic-solutions-for-addressing-non-communicable-diseases-in-low--an-peer-reviewed-article-JMDH

32. Aminian S, Hinckson EA. Examining the validity of the ActivPAL monitor in measuring posture and ambulatory movement in children. International Journal of Behavioral Nutrition and Physical Activity. 2012;9:1–9.

33. Arts J, Drotos E, Singh AS, Chinapaw MJM, Altenburg TM, Gubbels JS. Correlates of Physical Activity in 0- to 5-year-olds: A Systematic Umbrella Review and Consultation of International Researchers. Sports Medicine [Internet]. 2023;53(1):215–40. Available from: https://doi.org/10.1007/s40279-022-01761-5

34. Tapia-Serrano MA, Sevil-Serrano J, Sánchez-Miguel PA, López-Gil JF, Tremblay MS, García-Hermoso A. Prevalence of meeting 24-hour movement guidelines from pre-school to adolescence: A systematic review and meta-analysis including 387,437 participants and 23 countries. J Sport Health Sci. 2022;11(4):427–37.

35. World Health Organization. World Health Organisation Guidelines for physical activity, sedentary behaviour, and sleep for children under 5 years of age [Internet]. 2019 [cited 2024 Mar 13]. Available from: https://www.who.int/publications/i/item/9789241550536

36. Cyril S, Oldroyd JC, Renzaho A. Urbanisation, urbanicity, and health: A systematic review of the reliability and validity of urbanicity scales. BMC Public Health. 2013;13(1).

37. Msyamboza KP, Ngwira B, Dzowela T, Mvula C, Kathyola D, Harries AD, et al. The Burden of Selected Chronic Non-Communicable Diseases and Their Risk Factors in Malawi: Nationwide STEPS Survey. Su Z, editor. PLoS One [Internet]. 2011 May 23 [cited 2025 Mar 29];6(5):e20316. Available from: https://dx.plos.org/10.1371/journal.pone.0020316

38. Gowshall M, Taylor-Robinson SD. The increasing prevalence of non-communicable diseases in low-middle income countries: The view from Malawi. Vol. 11, International Journal of General Medicine. Dove Medical Press Ltd.; 2018. p. 255–64.

39. Kankeu HT, Saksena P, Xu K, Evans DB. The financial burden from non-communicable diseases in low- and middle-income countries: A literature review. Vol. 11, Health Research Policy and Systems. 2013.

40. Munthali AC, Mvula PM, Silo L. Early childhood development: The role of community based childcare centres in Malawi. Springerplus. 2014;3(1):1–10.

41. Kristen Devlin, Pandit-Rajani T, Egan KF. Malawi’s Community-based Health System Model: Structure, Strategies, and Learning. 2017.

42. Ministry of Health. National Community Health Strategy 2017-2022: Integrating health services and engaging communities for the next generation [Internet]. Lilongwe; 2017. Available from: https://www.healthynewbornnetwork.org/hnn-content/uploads/National_Community_Health_Strategy_2017-2022-FINAL.pdf

43. Nusurupia J, J. RJ, Xanne J. Pre-school children’s compliance with the WHO 24-hour movement behaviour guidelines: a systematic review of Sub-Saharan African studies. African Journal for Physical Activity and Health Sciences (AJPHES) [Internet]. 2020 Dec 1;26(4):345–59. Available from: https://doi.org/10.10520/ejc-ajpherd1-v26-n4-a2

44. Reilly JJ, Andrew R, Abdeta C, Azevedo LB, Farias NA, Barak S, et al. Improving National and International Surveillance of Movement Behaviours in Childhood and Adolescence: An International Modified Delphi Study. Sports Medicine [Internet]. 2024 Oct 3; Available from: https://link.springer.com/10.1007/s40279-024-02104-2

45. Hossain MS, Deeba IM, Hasan M, Kariippanon KE, Chong KH, Cross PL, et al. International study of 24-h movement behaviors of early years (SUNRISE): a pilot study from Bangladesh. Pilot Feasibility Stud. 2021;7(1):1–9.

46. Byambaa A, Dechinjamts O, Jambaldorj B, Jones RA, Chong KH, Okely AD. Prevalence and Health Associations of Meeting the World Health Organization Guidelines for Physical Activity, Sedentary Behavior, and Sleep in Preschool-Aged Children: The SUNRISE Mongolia Pilot and Feasibility Study. J Phys Act Health. 2024;21(3):283–93.

47. Kim T V., Pham TND, Nguyen CLD, Nguyen TTD, Okely AD, Tang HK. Prevalence of physical activity, screen time, and sleep, and associations with adiposity and motor development among preschool-age children in Vietnam: The SUNRISE Vietnam pilot study. Indian J Pediatr [Internet]. 2022;89(2):148–53. Available from: https://doi.org/10.1007/s12098-021-03895-2

48. Cardon G, De Bourdeaudhuij I. Comparison of Pedometer and Accelerometer Measures of Physical Activity in Preschool Children. Pediatr Exerc Sci. 2007;19:205–14.

49. Trost SG. Population-level physical activity surveillance in young people: Are accelerometer-based measures ready for prime time? Vol. 17, International Journal of Behavioral Nutrition and Physical Activity. BioMed Central Ltd.; 2020.

50. Decraene M, Verbestel V, Cardon G, Iotova V, Koletzko B, Moreno LA, et al. Compliance with the 24-hour movement behavior guidelines and associations with adiposity in european preschoolers: Results from the toybox-study. Int J Environ Res Public Health. 2021;18(14).

51. Zhang Z, Abdeta C, Chelly MS, del Pozo Cruz J, Engberg E, Germana L, et al. Measurment properties of the SUNRISE Study Parent Questionnaire for assessing sleep and sleep-related family practices. Sleep Health: Journal of the National Sleep Foundation. 2025;

52. Sallis JF, Owen N, Fisher EB. Ecological models of health behaviour. In: Glanz K, Rimer BK, Viswanath K., editors. Health behavior and health education: theory, research, and practice. 4th ed. San Francisco; 2008. p. 465–85.

53. National Statistical Office. Malawi Multiple Indicator Cluster Survey 2019-20, Survey Findings Report. [Internet]. Zomba; 2021 [cited 2023 Jul 22]. Available from: https://www.nsomalawi.mw/publications/health/multiple-indicator-cluster-survey-2019-20

54. Government of Malawi. National Policy for Early Childhood Development [Internet]. Lilongwe; 2017 [cited 2025 Mar 25]. Available from: https://faolex.fao.org/docs/pdf/mlw219889.pdf

Appendix A: SUNRISE International Study protocol

Open access Protocol

BMJ Open

Cross-sectional examination of 24-hour movement behaviours among 3- and 4-year-old children in urban and rural settings in low-income, middle-income and high-income countries: the SUNRISE study protocol

Tony Okely,[1] John J Reilly,[2] Mark S Tremblay,[3] Katharina E Kariippanon,[1] Catherine E Draper,[4] Asmaa El Hamdouchi,[5] Alex A Florindo,[6] Janette P Green,[7] Hongyan Guan,[8] Peter T Katzmarzyk,[9] Himangi Lubree,[10] Bang Nguyen Pham,[11] Thomas Suesse,[12] Juana Willumsen,[13] Mohamed Basheer,[14] Rebecca Calleia,[14] Kar Hau Chong,[14] Penny L Cross,[14] Maria Nacher,[14] Laura Smeets,[14] Ellie Taylor,[14] Chalchisa Abdeta,[15] Nicolas Aguilar-Farias,[16] Aqsa Baig,[17] Jambaldorj Bayasgalan,[18] Cecilia H S Chan,[19] P W Prasad Chathurangana,[20] Michael Chia,[21] Fazlollah Ghofranipour,[22] Amy S Ha,[23] Mohammad Sorowar Hossain,[24] Xanne Janssen,[25] Alejandra Jáuregui,[26] Piyawat Katewongsa,[27] Dong Hoon Kim,[28] Thanh Van Kim,[29] Denise Koh,[30] Anna Kontsevaya,[31] Germana H Leyna,[32] M Löf,[33,34] Nyaradzai Munambah,[35] Tawonga Mwase-Vuma,[36] Jackline Nusurupia,[32] Aoko Oluwayomi,[37] Borja del Pozo-Cruz,[38] Jesus del Pozo-Cruz,[39] Eva Roos,[40,41] Asima Shirazi,[42] Pragya Singh,[43] Amanda Staiano,[9] Adang Suherman,[44] Chiaki Tanaka,[45] Hong Kim Tang,[46] Wei-Peng Teo,[21] Marites M Tiongco,[47] Dawn Tladi,[48] Ali Turab,[17] Sanne L C Veldman,[49] E Kipling Webster,[50] Pujitha Wickramasinghe,[51] Dyah Anantalia Widyastari[27]

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For numbered affiliations see end of article.

Correspondence to
Tony Okely; tokely@uow.edu.au

ABSTRACT

Introduction 24-hour movement behaviours (physical activity, sedentary behaviour and sleep) during the early years are associated with health and developmental outcomes, prompting the WHO to develop Global guidelines for physical activity, sedentary behaviour and sleep for children under 5 years of age. Prevalence data on 24-hour movement behaviours is lacking, particularly in low-income and middle-income countries (LMICs). This paper describes the development of the *SUNRISE International Study of Movement Behaviours in the Early Years* protocol, designed to address this gap.

Methods and analysis SUNRISE is the first international cross-sectional study that aims to determine the proportion of 3- and 4-year-old children who meet the WHO Global guidelines. The study will assess if proportions differ by gender, urban/rural location and/or socioeconomic status. Executive function, motor skills and adiposity will be assessed and potential correlates of 24-hour movement behaviours examined. Pilot research from 24 countries (14 LMICs) informed the study design and protocol. Data are collected locally by research staff from partnering institutions who are trained throughout the research

Strengths and limitations of this study

- First known multi-country cross-sectional study using new WHO guidelines on physical activity, sedentary behaviour and sleep for children under 5 years of age, informing global efforts to develop culturally specific interventions to improve movement behaviours and ensure young children reach their health and developmental potential.
- Objective, device-based measures of 24-hour movement behaviours and direct measures of executive function, motor skills and adiposity in a sample of urban and rural communities from predominantly low-income and middle-income countries undergoing rapid urbanisation.
- Almost exclusive sampling of children attending Early Childhood Education and Care services may not be representative of the general population in some countries.

Strengths and limitations of this study

- A generic parent questionnaire may not be sensitive enough to identify the contextual nuances necessary to understand the patterns, prevalence and correlates of movement behaviours.
- Reliance on data management platforms that require reliable internet connectivity is a challenge in some regions.

process. Piloting of all measures to determine protocol acceptability and feasibility was interrupted by COVID-19 but is nearing completion. At the time of publication 41 countries are participating in the SUNRISE study.
Ethics and dissemination The SUNRISE protocol has received ethics approved from the University of Wollongong, Australia, and in each country by the applicable ethics committees. Approval is also sought from any relevant government departments or organisations. The results will inform global efforts to prevent childhood obesity and ensure young children reach their health and developmental potential. Findings on the correlates of movement behaviours can guide future interventions to improve the movement behaviours in culturally specific ways. Study findings will be disseminated via publications, conference presentations and may contribute to the development of local guidelines and public health interventions.

INTRODUCTION

The early years (defined as <5 years) are arguably the most critical period in life for developing important physical, motor, social and cognitive skills.[1] As a sensitive period of brain development, this period in life provides a window of opportunity where developmental plasticity can be exploited to positively influence the trajectory of a child's life in each of the above developmental areas, and to reduce health inequities.[2] However, it is also a period for which, despite advances in technology, many gaps still exist in the evidence base.

Consider a young child's physical and motor development in the context of how they move throughout a typical day. It is a combination of sleep, sitting, standing and different intensities of physical activity, the latter mostly in the form of play and other activities of daily living. Little is known about how these behaviours—individually and in combination—influence one another and how they relate to healthy growth and development.[3] The dearth of information is even more pronounced in low-income and middle-income countries (LMICs),[4] many of which are in a period of rapid urbanisation that may further impact the healthy development of these behaviours among this age group.[5 6]

The WHO has identified the prevention of obesity in young children as one of its key priorities for the 21st century[3]; movement behaviours play a key role in this priority. A specific recommendation from the WHO Report of the Commission on Ending Childhood Obesity (rec 4.12)[3] was to develop international guidelines for movement behaviours for the early years (<5 years). This is especially important for LMICs, where awareness of the importance of healthy levels of these behaviours in the early years is low, and benchmarks to determine their prevalence are lacking. In response to this recommendation and the growing evidence on the relationship between physical activity,[1] sedentary behaviour[3] and sleep duration[7] individually, and in combination,[4] and health indicators in the early years, the WHO released the first guidelines for physical activity, sedentary behaviours and sleep for children under 5 years of age, in April 2019.[8] These guidelines are based on an integrated movement behaviour paradigm[9] and provide recommendations for each of the three movement behaviours (physical activity, sedentary behaviour and sleep) across a 24-hour period, aligning with national recommendations from countries such as Canada[10] and Australia.[11]

Systematic reviews of studies investigating the relationship between movement behaviours and health indicators have reported that the overwhelming majority were conducted in high-income countries (HICs), even multi-country studies, with very few conducted in LMICs and virtually none comparing HICs with LMICs.[4 12] It is not known how urbanisation and economic development, particularly in LMICs, is associated with young children's movement behaviours.[13] Globally, it is estimated that 70% of people will live in cities by 2050 and that most of these people will be children or adolescents.[6] The majority of this increase in urbanisation will occur in LMICs, and there is concern over how this will be managed. Key challenges particularly in urban environments, such as traffic, pollution, crime, social fears, employment demands, inequitable access to adequate and healthy foods and urban sprawl, may all negatively affect movement behaviours, making it easier for young children to adopt unhealthy levels of these behaviours. In LMICs, there is less likely to be the infrastructure, health and social services, education, economic or policy support to ensure that these core challenges are addressed.[6]

Rapid urbanisation and high population densities reduce green spaces and public playgrounds, worsen air and noise pollution, increase motorised transportation and reduce walkability, which make outdoor physical activity less safe for children.[5 6 14] Sleep duration and quality might also be affected in settings with high population densities, because children often share bedrooms and beds and are more exposed to electronic media in these spaces.[15] Many families transitioning to cities also desire for their children to have technology-centric lifestyles often seen in HICs, resulting in children engaging in long periods of sedentary screen time that probably replaces active play and increases exposure to marketing of unhealthy foods.[16] Not only does this place children at possible risk of overweight and obesity but healthy child development may be compromised due to lack of play and sleep opportunities.

A systematic review[4] of studies examining adherence to 24-Hour Movement Guidelines among preschoolers (ages 3 and 4 years), reported that of the nine studies, all from HICs, between 5%–24% met all three of the daily movement guidelines for this age group: (1) at least 180 min of physical activity, of which at least 60 min is energetic play, (2) no more than 1 hour of

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sedentary screen time and (3) 10–13 hours of good quality sleep. Prior to the conception of the SUNRISE study there were only two known studies[17 18] from LMICs that had examined compliance with the 2019 WHO guidelines. A Brazilian study reported that physical activity compliance was the highest at 43%, with 35% and 15% meeting sleep and sedentary screen time recommendations respectively, while only 3% of preschoolers met all three recommendations.[17] A study among Chinese kindergarteners found the proportion of children who met the physical activity, sedentary screen time and sleep guidelines were 65%, 88% and 29%, respectively, with only 15% meeting all three guidelines and 2.7% not meeting any of the guidelines.[18]

For these reasons, the *SUNRISE International Study of Movement Behaviours in the Early Years* (https://sunrise-study.com) was designed to collect data on the movement behaviours of preschool-aged children, the factors that are related to these behaviours and how the movement behaviours are associated with obesity and other health and developmental outcomes in a large-scale international sample of urban and rural communities. The primary aim of the SUNRISE study is to determine the proportion of 3- and 4-year-old children sampled in participating countries who meet the WHO Global guidelines for physical activity, sedentary and sleep behaviour.[8] Further, the study aims to determine if these proportions differ by gender, parental education level, urban/rural location and among countries of differing human and economic development.

As a secondary aim, associations between 24-hour movement behaviours and health and development outcomes will be examined. These outcomes include overweight and obesity, gross and fine motor skills and executive function. These secondary aims have been chosen because significant associations have also been found between the composition of 24-hour movement behaviours and indicators of adiposity and bone and skeletal health among preschoolers.[4] There is also emerging evidence from a number of countries that the prevalence of developmental delay in important domains such as motor and physical development are high, around 15% for gross motor skills and up to 32% for fine motor skills.[19–22] In addition the study seeks to determine potential correlates of 24-hour movement behaviours using a social ecological model, to examine inter-relationships between individuals and the social (eg, family, safety, noise, Early Childhood Education and Care (ECEC)), physical (eg, urban/rural, air quality, outdoor play space) and policy (ECEC policies on food, play, screen time) environment.[23] An overarching goal of SUNRISE is the co-creation of new knowledge and building an international network of researchers interested in 24-hour movement behaviour of young children. This paper aims to describe the protocol of the SUNRISE study, detailing how the different iterations of the *pilot study phases* have contributed to finalising the methods and measures to be used in the SUNRISE *main study*.

METHODS AND ANALYSIS

Project leadership and management

SUNRISE is guided by an international Leadership Group (see online supplemental table 1) comprising a member from each UN Sustainable Development Goal region (sub-Saharan Africa, Northern Africa and Western Asia, Europe and Northern America, Central and Southern Asia, Eastern and South-Eastern Asia, Oceania, Australia and New Zealand, Latin America and the Caribbean). The group is gender balanced and includes early/mid-career and late-career researchers from low, middle and high-income countries, along with a project statistician and quality assurance expert, WHO representative and an external advisor. The Leadership Group is responsible for developing the protocols for the study, including but not limited to ethical considerations, sampling units and recruitment, governance, budget, data management, training of staff, quality assurance, communications and publications. Video conference meetings are held bimonthly, with the Leadership Executive, made up of three members of the Leadership Group meeting during the alternate months. The SUNRISE Coordinating Centre based at the University of Wollongong (UOW), Australia, is responsible for the overall administration and of the study. This centre comprises a data manager, project, research and equipment officers, a programmer and postdoctoral fellows.

Sample selection

SUNRISE is an international cross-sectional study that aims to recruit approximately 1000 healthy, gender balanced children aged 3 and 4 years from each participating country, with equal numbers (500 each) from urban and rural communities representing low-income, middle-income and high-income countries from each major geographical region of the world (see table 1). Countries have been recruited from each of the four levels of the World Bank income classifications (low, middle, high and very high). There has been an effort to spread countries geographically and by income status. Asia and Africa are highly-represented in the sample as 90% of the anticipated increase in the global urban population will occur in these regions over the next 30 years.[24]

Recruitment of countries into the SUNRISE study has occurred on a continuous basis. Initially countries were recruited by members of the SUNRISE Leadership Group through existing collaborations. The Leadership Group met in Hong Kong in August 2017 to develop the first iteration of the study protocol. A SUNRISE workshop was held at the 2018 International Society of Behavioral Nutrition and Physical Activity meeting in Hong Kong to introduce the study to the international research community and further recruitment occurred at subsequent conferences,

Table 1 SUNRISE participating country characteristics

Country	WHO region	World Bank classification*	Local institution	Location of local institution	Settings for data collection in pilot study	Chief investigator
Botswana	AFRO	Upper-middle income	University of Botswana	Gaborone, Botswana	Urban: Gaborone city Rural: Greater Gaborone district	Dawn Tladi
Ethiopia	AFRO	Low-income	Adama Hospital Medical College	Adama, Ethiopia	To be determined	Chalchisa Abdeta
Kenya	AFRO	Lower-middle income	Wellness for Greatness, Kenya	Nairobi, Kenya	To be determined	Amonje Moses Oluchiri
Malawi	AFRO	Low-income	Centre for Social Research, University of Malawi	Zomba, Malawi	Urban: Lilongwe, Central Malawi Rural: Karonga, Northern Malawi	Tawonga Mwase-Vuma
Nigeria	AFRO	Lower-middle income	University of Lagos	Lagos, Nigeria	Urban: Southwest Region (Lagos State) Rural: Southwest Region (Lagos State)	Aoko Oluwayomi
South Africa	AFRO	Upper-middle income	University of the Witwatersrand	Johannesburg, South Africa	Urban: Soweto, Johannesburg, Gauteng province Rural: Sweetwaters, KwaZulu-Natal province	Catherine Draper
Tanzania	AFRO	Lower-middle income	Tanzania Food and Nutrition Center	Dar es Salaam, Nairobi	Urban: Ukonga/Gongolamboto Dar es Salaam Rural: To be determined	Germana Leyna Jackline Nusurupia
Zimbabwe	AFRO	Lower-middle income	University of Zimbabwe	Harare, Zimbabwe	Urban: Ruwa, Mashonaland East province Rural: Domboshava, Mashonaland East province	Nyaradzai Munambah
Iran	EMRO	Upper-middle income	Tarbiat Modares University	Tehran, Iran	To be determined	Fazlollah Ghofranipour
Morocco	EMRO	Lower-middle income	Unite Mixte de Recherche en Nutrition et Alimentation	Rabat, Morocco	Urban: Rabat-Salé-kénitra Region Rural: Rabat-Salé-kénitra Region	Asmaa El Hamdouchi
Pakistan	EMRO	Lower-middle income	Precision Health Consultants Global	Karachi, Pakistan	Urban: Karachi West and Central Districts Rural: Larkana, Sindh, Pakistan	Ali Turrab Aqsa Baig
United Arab Emirates	EMRO	High-income	University of Wollongong - Dubai	Dubai, UAE	Urban: Dubai, Abu Dhabi, Sharjah, Ras al Khaimah	Asima Shirazi
Finland	EURO	High-income	Folkhälsan Research Center	Helsinki, Finland	Urban: Uusimaa county, Southwest Finland county Rural: Uusimaa county, Southwest Finland county	Eva Roos

Continued

Table 1 Continued

Country	WHO region	World Bank classification*	Local institution	Location of local institution	Settings for data collection in pilot study	Chief investigator
The Netherlands	EURO	High-income	Amsterdam University Medical Centre	Amsterdam, Netherlands	Urban: Amsterdam area Rural: Outside the Randstad area	Sanne Veldman
Poland	EURO	High-income	Institute of Mother and Child	Warsaw, Poland	To be determined	Hanna Nalecz
Russia	EURO	Upper-middle income	National Research Center for Therapy and Preventive Medicine	Moscow, Russia	Urban: Tver Region	Anna Kontsevaya
Scotland	EURO	High-income	University of Strathclyde	Glasgow, Scotland	Urban: Greater Glasgow Rural: Dumfries and Galloway, Argyll and Bute	John Reilly Xanne Janssen
Spain	EURO	High-income	University of Seville	Seville, Spain	Urban: Valencia and Sevilla provinces Rural: Valencia and Sevilla provinces	Jesus del Pozo Cruz Borja del Pozo Cruz
Sweden	EURO	High-income	Karolinska Institute	Stockholm, Sweden	Urban: Stockholm county Rural: Östergötland county	Marie Löf
Brazil	PAHO	Upper-middle income	University Sao Paulo	Sao Paulo, Brazil	Urban: Sao Paulo municipality Rural: Itabiba municipality	Alex Antonio Florindo
Canada	PAHO	High-income	Children's Hospital of Eastern Ontario Research Institute	Ottawa, Ontario, Canada	Urban: Ottawa city Rural: Ottawa city surrounds	Mark Tremblay
Chile	PAHO	High-income	Universidad de La Frontera	Temuco, Chile	Urban: Cautin province, Araucania region Rural: Cautin province, Araucania region	Nicolas Aguilar-Farias
Mexico	PAHO	Upper-middle income	Instituto Nacional de Salud Pública	Cuernavaca, Mexico	Urban: Cuernavaca city Rural: Cuernavaca city surroundings	Alejandra Jáuregui
United States	PAHO	High-income	Pennington Biomedical Research Center and Augusta University	Baton Rouge, Louisiana; Augusta, Georgia	Urban: Louisiana, Southeastern Region Rural: Georgia, Southeastern Region	Amanda E. Staiano E.Kipling Webster
Bangladesh	SEARO	Lower-middle income	Biomedical Research Foundation	Dhaka, Bangladesh	Urban: Dhaka district Rural: Dhaka district	Mohammad Sorowar Hossain
India	SEARO	Lower-middle income	Kem Hospital Research Centre	Pune, India	Urban: Pune city Rural: Vadu, Shirur Taluka of Pune district	Himangi Lubree
Indonesia	SEARO	Lower-middle income	Universitas Pendidikan Indonesia	Jawa Barat, Indonesia	Urban: Province of West Java Rural: Province of West Java	Adang Suherman

Continued

Table 1 Continued

Country	WHO region	World Bank classification*	Local institution	Location of local institution	Settings for data collection in pilot study	Chief investigator
Sri Lanka	SEARO	Upper-middle income	University of Colombo	Colombo, Sri Lanka	Urban: Colombo Rural: Homagama	Pujitha Wickramasinghe Prasad Chathurangana
Thailand	SEARO	Upper-middle income	Mahidol University	Naknon Pathom, Thailand	Urban: Bangkok region Rural: Central region	Piyawat Katewongsa Dyah Anantalia Widyastari
Australia	WPRO	High-income	Early Start, University of Wollongong	Wollongong, Australia	Urban: Wollongong and Sydney Rural: South Coast NSW	Tony Okely
China	WPRO	Upper-middle income	Capital Institute of Pediatrics	Beijing, China	Urban: Shijinshan district (Beijing) Rural: Huairou district and Fangashan district (Beijing)	Hongyan Guan
Fiji	WPRO	Upper-middle income	Fiji National University	Suva, Fiji	To be determined	Pragya Singh
Hong Kong	WPRO	High-income	The Chinese University of Hong Kong	Shatin, N.T. Hong Kong	Urban: Hong Kong Island, Kowloon and the New Territories	Amy S Ha Cecilia Chan
Japan	WPRO	High-income	J.F. Oberlin University	Tokyo, Japan	Urban: Kyoto and Okinawa prefectures Rural: Nagano and Okinawa prefectures	Chiaki Tanaka
Korea Republic	WPRO	High-income	Korea Institute of Child Care and Education	Seoul, Korea	Urban: Seoul city and Gyeonggi provinces Rural: Gyeonggi and North Chungcheong provinces	Dong Hoon Kim
Malaysia	WPRO	Upper-middle income	Universiti Kebangsaan Malaysia	Bangi, Selangor, Malaysia	Urban: Kuala Lumpur, Nilai, Bangi Rural: Kuala Selangor	Denise Koh
Mongolia	WPRO	Lower-middle income	National Center for Public Health	Ulaanbaater, Mongolia	Urban: Ulaanbaatar, Khentii Rural: Bayanzurkh, Khentii	Jambaldori Bayasgalan
Papua New Guinea	WPRO	Lower-middle income	Papua New Guinea Institute of Medical Research	Goroka, Papua New Guinea	Urban: Goroka, Eastern Highlands Province Rural: Asaro, Eastern Highlands Province	Bang Nguyen Pham
Philippines	WPRO	Lower-middle income	De La Salle University	Manila, Philippines	Urban: Manila Rural: Region 4A, Region 3	Marites Tiongco
Singapore	WPRO	High-income	National Institute of Education, Nanyang Technological University	Singapore	Urban: Punggol and SengKang	Michael Chia Wei-Peng Teo

Continued

Table 1 Continued

Country	WHO region	World Bank classification*	Local institution	Location of local institution	Settings for data collection in pilot study	Chief investigator
Vietnam	WPRO	Lower-middle income	Pham Ngoc Thach University of Medicine	Ho Chi Minh City, Vietnam	Urban: District Tân Bình and District 1, Ho Chi Minh city Rural: District Bình Chánh and District Nhà Bè, Ho Chi Minh city	Hong Kim Tang Thanh Van Kim

*Obtained from the World Bank. Data—World Bank Country Lending Groups, 2020.
AFRO, African region; EMRO, Eastern Mediterranean region; EURO, European region; PAHO, Pan-American region; SEARO, South-east Asian region; WPRO, Western Pacific region.

through word of mouth and professional and research student networks. Participating countries have therefore either been actively invited or have expressed interest in participating. In each country a partnering institution and local chief investigator (CI) are identified who take responsibility for all aspects of conducting the study at the local level.

Given the vastly differing contexts in which SUNRISE is being conducted, the local CI and research team in each country determine the most appropriate approach to recruiting children of consenting parents/caregivers into the study. This occurs using a convenience cluster sampling approach either through ECEC services, or from the community at a village level. This has occurred in some LMIC rural locations where ECEC services are limited. The sampling frame for each country comprises a geographical area within reasonable travel distance from the CIs institution. If recruitment is conducted through ECEC services, then the primary sampling unit is the ECEC service. In countries where children will be exclusively recruited from both public and private ECEC centres, a maximum of 20 children per centre will be recruited to ensure there is variability within the sample.[25] This will result in a minimum of 50 public and/or private centres participating in the main study. Services will not be randomly selected but countries do need to ensure that the sample is broadly representative of the country in terms of sex, socioeconomic backgrounds of parents[25] and urban/rural residence.[26] All children in the selected ECECs or villages who are within the age range and who can wear an accelerometer are eligible to participate. There are no other exclusion criteria.

Pilot study

To be eligible for participation in the SUNRISE *main study* each country is required to conduct a *pilot study* to assess the feasibility and acceptability of the study protocol, particularly recruitment and data collection methods. For the pilot study, 100 children aged 3 and 4 years are recruited equally from urban and rural settings (50 children from each). Each country is advised to use the national definition of the country to determine what is an urban and rural area. These are typically official definitions. This sample size has been deemed sufficient to test the feasibility of the protocol in each setting. In addition to completing all measures proposed for the main study, the pilot study protocol also includes a survey providing information about the settings in which children spend time and the research team's ability to recruit the required sample in an urban and rural area. Several focus groups are conducted in each country with key stakeholders such as parents and ECEC service staff to discuss the acceptability of the measures and the study protocol. Findings from the focus groups (see table 2) have been used to modify the protocol and refine the measures. Results from the pilot studies are also being used for subsequent funding applications for the SUNRISE main study at a country level as well as collectively.

Table 2 Focus group and interview findings

Key themes	Main points	Implications for study protocol
Facilitators for childcare centre staff	Study involvement novel and enjoyable.	Confirms the acceptability and appropriateness of the measures and data collection procedures.
Barriers for ECEC service staff	Multiple data collection sessions per participant; keeping track of accelerometers challenging due to large sample; lack of familiarity with wearable technology; limited space within centres and distraction from non-participating children.	During the SUNRISE training, data collectors are advised to administer the assessments tasks to suit each centre programme/schedule, data collector's schedule as required; data collectors trained on device safety and participation ethics.
Parent feedback on questionnaire	Questions were understood and the support of data collectors and translation into local language assisted comprehension; challenges around estimating time spent in PA during time when kids are at the centre; estimation difficult due to seasonality of PA.	Translation of questions into local language as feasible; provide time ranges as response options; adding seasons/time of year to questionnaire; providing link to video instructions on accelerometer use for parents.
Children's overall feedback on participation	Parents and ECEC staff both reported that children enjoyed participating in the study.	Confirms the acceptability and appropriateness of the measures and data collection procedures.
Feedback on accelerometers	Responses to the accelerometers varied. Most found the monitors interesting and children were excited and proud to wear them. Challenges included placement of activPAL monitor on thigh, discomfort, irritation, difficulties dressing, bathing and sleeping, several reports of rashes and wear time compliance.	Use of the activPAL (placed on thigh) was stopped for *Phase II* and ActiGraph (belt around waist) was used exclusively. For *Phase III* all children will wear the ActiGraph on the hip.
Feedback on motor skills tasks	Motor skills were seen as age-appropriate and informative for educators about children's strengths and weaknesses. Children enjoyed the tasks.	Confirms the acceptability and appropriateness of the measures and data collection procedures.
Feedback on executive function tasks	The iPad games were generally perceived as fun and age appropriate. Variability among children sustaining interest due to considerable differences in exposure to devices between countries.	Choice of iPad tasks to be appropriate for most children regardless of previous device exposure. Data collectors trained to support children to feel comfortable in using unfamiliar tools.

ECEC, Early Childhood Education and Care; PA, physical activity.

Patient and public involvement

Since the aim of the pilot work is in part to test and refine the study protocol based on local contexts, data collected have been analysed and used to refine the methods and measures over time. Consequently, there have been three distinct pilot phases for this study. A total of 8 countries participated in *Phase I* from March 2018 to July 2019, 12 countries participated in *Phase II* from August 2019 to September 2020 and 21 countries are currently involved in *Phase III* of the pilot study (see figure 1 for map of participating countries). Table 3 highlights the main changes that have been made to the protocol across the three phases. Changes were made based on feedback that was obtained through the focus groups with parents and ECEC service staff as well as feedback from local research teams.

The COVID-19 pandemic has resulted in delays for several countries conducting the pilot study. Consequently, there will be some countries still trialling the protocol, while others will commence with the main study. Any additional countries wishing to participate in SUNRISE will use the *Phase III* protocol for their pilot study and this will also be used in the main study. Additional questions have been added to the protocol to capture the influence of COVID-19 on the movement behaviours in the ECEC setting (see online supplemental table 2).

Training and capacity building

Face-to-face training sessions organised for all country CIs and key local staff are conducted by the SUNRISE Coordinating Centre in advance of data collection in each country. All staff working on the study receive 2 days of training in all steps of the data collection process with particular emphasis on the administration of all assessments in this age group. Data collectors are certified by trained experts as competent to make the required

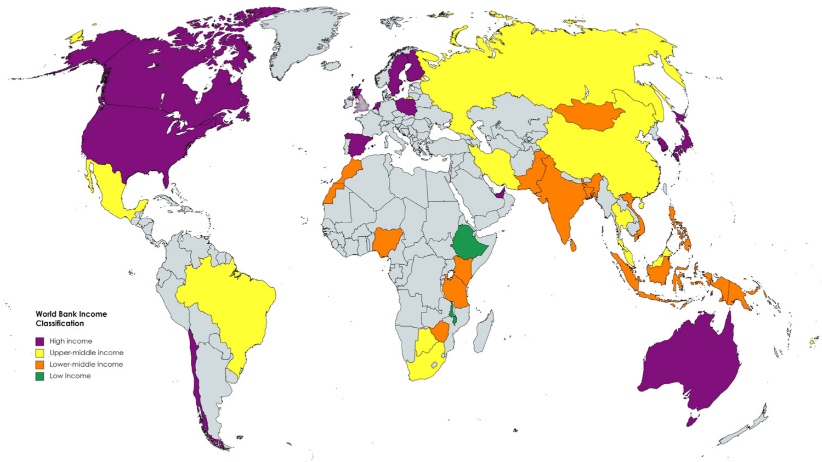

Figure 1 Map of participating countries.

measurements. This involves the watching of online training videos, observation by trainers of data collectors practicing the assessments on children, viewing protocol videos and successfully completing a test on the assessment protocol as part of the face-to-face training by experts. The CIs from each country are mentored throughout the entire research and surveillance process (see below).

Since August 2020, due to ongoing COVID-19-related travel restrictions, the training sessions have been adapted for online delivery. Training sessions for staff in have been held for the SUNRISE teams in Singapore, Russia and Nigeria. To facilitate this, videos have been developed to demonstrate the assessment protocols and practice assessments are conducted over Zoom or recorded and sent to the coordinating centre for feedback. These are publicly available on the SUNRISE YouTube channel (https://www.youtube.com/channel/UCUgmfAGHO1qW7HV73vDVSLw).

Measures

The measures described below are those used in *Phase III* of the protocol development.

Primary outcome

Twenty-four-hour movement behaviours (physical activity, sedentary time and sleep) are assessed using accelerometry[27] (see table 3 for the types of accelerometers trialled). For the main study, the ActiGraph (*GT3X, GT3X+*) accelerometer will be used. This waist worn device is the most widely used and extensively validated accelerometer for physical activity, sedentary behaviour[28] and sleep assessment.[29] A pool of accelerometers is made available for use across countries. Children are asked to wear the device continuously (including sleeping and while engaging in water-based activities such as bathing and swimming) for a minimum of 5 days to get three full days (3×24-hour period) of data. This will provide data on total physical activity, moderate-intensity to vigorous-intensity physical activity, total sitting time and total lying time.

In addition, some components of the 24-hour movement behaviours are reported by the primary caregiver on behalf of the participating child. These questions were originally developed based on the recommendations for each behaviour guideline.[11] The brief survey, which takes about 15–20 min to complete, asks the caregiver about the child's physical activity (only asked in Phase I), bed, wake and nap times (from which sleep-time is calculated), use of electronic media and restrained sitting (to calculate sedentary time) (see online supplemental table 3).

Secondary outcomes

A range of health and development outcomes will be obtained to assess associations with 24-hour movement behaviours:

Anthropometry—height and weight are measured to the nearest millimetre and kilogram using a portable stadiometer and an electronic, calibrated scale following standardised procedures as per WHO protocols.[30]

Gross and fine motor skills will be measured via validated activities from the National Institute of Health (NIH) Toolbox.[31] All measures are scored as outlined by the NIH Toolbox protocol. Five tests are included.

Gross motor skills

- Children perform a *standing long jump* to determine lower body explosive strength and mobility. A line is marked on the floor and the child stands with their toes just behind the line. The child then jumps with two feet together as far as they can and lands on two feet. The child is given one practice and two test trials. A measurement is taken from the front of the line and the heel of the foot that is closest to the line. The distance is recorded to the nearest centimetre. The average of the distance values recorded is used.

Table 3 Pilot study phases

Countries	Measures	Reasons for modification of protocol
Phase I: 2018–2019		
Brazil Canada China Japan Korea Republic Papua New Guinea South Africa Zimbabwe	Child ► Anthropometry—height and weight. ► Executive Function Tests—Mr Ant, Go/NoGo, Dimensional Change Card Sort. ► Motor Skills (ASQ). ► 24-hour movement—ActiGraph, activPAL and Actical. Parent ► Parent/caregiver questionnaire. ► Focus groups. Centre staff ► Focus group.	N/A
Phase II: 2018–ongoing		
AustraliaBangladesh Hong Kong Indonesia Malaysia Morocco Scotland Spain Sri Lanka Sweden USA Vietnam	Child ► Anthropometry—height and weight. ► Executive Function Tests—Mr Ant, Go/NoGo, Dimensional Change Card Sort. ► 24-hour movement behaviour—ActiGraph. Parent ► Parent/caregiver questionnaire. ► Focus groups. Centre staff ► Focus groups.	Eight reports of minor skin irritation following use of the activPAL were reported in Canada, Bangladesh and Australia. Two other studies have also documented minor cases of skin irritation.[43 44] The actiGraph monitor will be used to objectively assess all movement behaviours (ie, sleep, sedentary time and physical activity). Monitor placement will be on the hip. Although the wear compliance rate is not as high as anticipated and there are challenges regarding night-time wear, easy removal of the device and analysis of the sleep data, strategies to resolve these matters are being worked on with the country teams. Parent proxy-report of their child's physical activity was dropped as many parents are not aware of the amount of physical activity their child participates in when at an ECEC service. Physical activity data are exclusively collected via accelerometry. The parent report question on total sleep time was broken down to capture, bed time, wake time and naps as we have found that the main time when children remove the accelerometer is when they go to bed so it provides us with some data on sleep for these children. Also, parent-reported information tends to report the time their child went to bed and got up which is different to the accelerometer which reports the time they went to sleep and woke up. Further parents also report on sedentary screen time as this cannot be assessed by accelerometry.
Phase III: 2019–ongoing		

Continued

Table 3 Continued

Countries	Measures	Reasons for modification of protocol
Botswana Ethiopia India Indonesia Iran Malawi Mexico Nigeria Netherlands Pakistan Russia Singapore Thailand Finland UAE Chile Fiji Tanzania Mongolia Philippines	Child ► Movement behaviours—ActiGraph. ► Anthropometry—height and weight. ► Executive Function Tests—Mr Ant, Go/NoGo. ► Motor skills (NIH Toolbox). Parent ► Parent/caregiver questionnaire. ► Food habits and eating behaviour questions added to survey. Centre staff ► Focus groups. ► Questionnaire.	The Dimensional Change Card Sort was dropped due to the time required to complete the tasks. The developers of the EYT advised that inhibition and working memory are the most salient measures of executive functions to measure in this age group. Elements from the non-proprietary NIH Toolbox were deemed more culturally feasible and will replace the ASQ to assess motor skills. Food habits and eating behaviour questions added to parent/caregiver questionnaire to provide additional context for interpreting anthropometric data. Centre questions added to gain more insight into the influences on movement behaviours in the child care centre setting.

ASQ, Ages and Stages Questionaire; ECEC, Early Childhood Education and Care; EYT, Early Years Toolbox; NIH, National Institute of Health.

- A *supine-timed up and go (STuG)* test is used to assess mobility and posture. A line is marked 3 m from a wall (using tape or chalk). A large target (circle or X) is marked on the wall at the child's eye level. The child lies supine (on their back) with their feet (heels) on the line. On 'go' the child is required to get up as quickly as possible, run and touch the target and run back across the 3 m line. The child has one practice and is then given two trials. Timing is started when the assessor says 'Go' and stopped as soon as the child's torso crosses the line. The average time taken to complete the task is used.
- A *one-legged standing balance test* is used to measure posture and balance. The child stands on one leg, with the arms held freely at the side of the body for up to 30 s. The child must keep the standing leg fixed but may keep the free leg in any position as long as it is off the floor. Hooking the free leg around the standing leg is not permitted. Swaying is allowed, and the arms may move from the sides but may not hold the free leg. Timing is started when the free leg leaves the floor. Timing is stopped if the child moves the standing leg or hooks the free leg around the other leg, or touches the free leg with their hands. If the child maintains balance for 30 s the assessment is stopped. The test is then repeated on the other leg. The length of time that the child is balancing on each leg is recorded. The average time spent balancing is used.
- A *handgrip dynamometer* (TKK5825, Grip-A, Takei, Tokyo) is used to assess upper extremity strength. The test measures the capacity of the hand and arm muscles to produce the tension and power necessary for maintaining posture, initiating movement or controlling movement during conditions of loading the musculoskeletal system. The child is required to squeeze the grip dynamometer continuously with full force with their right hand for at least 3 s without letting his/her arms touch their body. The test is then repeated with the left hand. The maximum measure attained is recorded.

Fine motor skills

The 9-hole pegboard test (PAT-A8515, Sammons Preston, Illinois, USA) is used to assess dexterity or manipulation. Dexterity is a central component of hand function and relates to both the speed and accuracy of hand movements. A child is timed picking up nine pegs one at a time and inserting them into the pegboard (31.1 cm × 26.0 cm × 4.3 cm). The test is then repeated with the left hand. The timer begins as soon as the assessor says 'Go' and is stopped as soon as the final peg is placed back in the well in the pegboard.

The 9-hole pegboard test and grip strength test are based on the assessments in the NIH Toolbox Motor Battery (ages 3–6).[31] The one-legged standing balance test and STuG were recommended as assessments for static balance and mobility (general mobility and locomotion), respectively. This recommendation was made by the Motor Domain Group in their proposal for assessment of motor function for mobility and posture for the National Children's Study (USA).[32] For assessment of mobility this Group recommended the vertical jump for age 5 onwards. On consultation with the lead author, it was recommended that a standing long jump be used for children under the age of 5. The standing long jump is widely used in motor development assessment batteries for this age group.[33 34]

Executive function

Inhibition and working memory, two key indicators of cognitive function, will be measured using the validated Early Years Toolbox (EYT).[35] Two brief, game-like assessment from the toolbox will be administered via an iPad and scored according to the EYT protocol.

- The *Go/No-Go* task is an assessment of 'inhibition'—the ability to control behavioural urges and impulses. Children are presented with fish and sharks and are instructed to tap the iPad screen whenever they see a Fish ('catch the fish') and refrain from responding when a Shark appears ('avoid the sharks').
- The *Mr Ant* task is an assessment of 'visual-spatial working memory'—the amount of visual information that can be concurrently coordinated in the mind. Children are presented with an image of a cartoon character—Mr Ant—who has a number of coloured dots placed in different spatial locations on his body. After a predetermined amount of time, these dots disappear, and the child is then asked to recall the locations of the dots by tapping the corresponding locations.

Parent questionnaire

In addition to the parent questionnaire on the child's 24-hour movement behaviour, standardised validated questions are asked of parents to assess potential correlates of 24-hour movement behaviour using a social ecological model, to examine inter-relationships between individuals, social, physical and physical environment.[23] This includes questions on the child's dietary diversity,[36] eating behaviour and food insecurity[37] at the family level. Further, sociodemographic information based on a modified version of the WHO STEPS survey[38] is recorded (see online supplemental table 3).

The questions assessing children's movement behaviours were based on the recommendations made by the surveillance subcommittee of the Guideline Development Group for the Australian 24-hour movement behaviour guidelines for the early years in 2017. The committee provided guidance on how to assess the proportion of children meeting the recommendations for each of the movement behaviours. The questionnaire in its entirety has not yet been validated.

ECEC service questionnaire

In settings where recruitment occurs at the ECEC service level, influences on 24-hour movement behaviour are assessed via a staff questionnaire. Questions cover the services' policies around food provision, the physical activity habits of the children and their sleep behaviour while at the ECEC service, to assess centre-level policy correlates of 24-hour movement behaviours (see online supplemental table 2).

All instruments were assessed for their cultural relevance and appropriateness, and in countries where English is not a first language, the instruments were translated by a native speaker and back-translated to ensure accuracy. Table 4 reports the initial results from the pilot studies including response rates for the main measures.

Outdoor air quality

Pollution levels will be measured at each participating ECEC service or at the village level during data collection using the Plume Labs application. The Plume mobile application, provides real-time pollution level data provided by environmental monitoring networks run by local and national governments around the world. Specifically, the application reports on particulate matter 2.5 (PM2.5), PM10 levels and give and overall air quality index. The purpose of this is to determine whether air quality is related to children's outside physical activity time and intensity during the day.

Data collection procedures

All data are collected by local data collectors in each country. A detailed protocol manual sets out the data collection instruments and procedures. To minimise errors caused by entering data from hard copy to electronic format, and to ensure data transfer efficiency, data are collected and managed using REDCap electronic data capture tools hosted at the UOW, Australia. REDCap (Research Electronic Data Capture) is a secure, web-based application designed to support data capture for research studies, providing: (1) an intuitive interface for validated data entry; (2) audit trails for tracking data manipulation and export procedures; (3) automated export procedures for seamless data downloads to common statistical packages; and (4) procedures for importing data from external sources.[39 40] One exception is the parent questionnaire, which is either completed by parents on paper or where literacy poses challenges, via interview, with the data entered directly into REDCap by the data collector. The Coordinating Centre loans iPads to participating countries with the REDCap projects and Early Years Toolbox games preloaded onto them.

Initial contact with individual ECEC service or village is made by a member of the local research team in each country. Dates for each service/village visit are then provided to all data collectors and local protocols for entering and exiting each service/village are followed.

As there are several measures to be taken with the children, the following order has been trialled and is recommended to ensure a smooth data collection process, giving children sufficient variability between tasks to sustain their engagement: (1) Executive function task (Mr Ant), (2) attach ActiGraph accelerometer, (3) measure height and weight, (4) assess gross motor skills, (5) assess fine motor skills and (6) executive function task 2 (GoNoGo). All measures are conducted on 1 day and take approximately 20 min to complete. It is not anticipated that participation in any measure will compromise the results of any subsequent measures.

Data in REDCap can be collected offline. To commence, the participant is allocated their unique study identification number. The consent form must then be completed which allows the remaining data to be collected and entered as per the suggested order. The data are saved as the data collector progresses through the various screens. The accelerometer monitor identification number is also entered to enable linking with the accelerometry data. Once all data have been collected and the iPad is able to be connected to the internet all data are sent to the project's REDCap server. From the server it is transferred to the UOW Coordinating Centre's databases for checking, and analysis. Comprehensive data guidelines that set out the principles, protocols, methods and procedure governing the management, access, use and dissemination of the data have been developed for the study.

Data analysis plan

Data on participant attributes such as demographic and anthropometric and movement behaviours will be summarised separately for boys and girls, and across urban and rural settings, as counts and percentages for categorical variables and means and SD for continuous variables. Given that the primary aim of the SUNRISE study is to determine the proportion of 3- and 4-year-old children sampled in participating countries who meet the WHO Global guidelines for physical activity, sedentary and sleep behaviour, prevalence estimates analysis will be conducted. We will also report the proportions who meet any combinations of the guidelines, including those who do not meet any recommendations. Linear and generalised linear models will be used for association analysis to assess whether associations exist (i) between meeting all (or any of the) guidelines and factors, such as sex (primary aims) and (ii) between health and development outcomes and 24-hour movement behaviours (secondary aims). The models will be covariate-adjusted, and treat ECEC service/villages within site and children within ECEC service/villages as well as ECEC service/villages within countries as random effects for all analyses. Statistical significance will be defined as $p<0.05$ with appropriate adjustments for multi-testing.

Main study sample size calculation

Data obtained from SUNRISE pilot studies from 17 countries, showed that the proportions of children meeting all components of the WHO Global guidelines varied across countries from 2.3% to 42.7% with a mean country proportion of 21.0%. These proportions also differed within many countries when comparing rural with urban

Table 4 Response rates from pilot studies as at article submission date

Country	Response rate	Total # of children	Mean # of children per ECEC	# of children with ≥1 days of '24 hours' data	% of children with ≥1 days of '24 hours' data	Response rates parent survey (%)	Gross motor skills (%)	Fine motor skills (%)	EYT (Mr Ant) (%)	EYT (GoNoGo) (%)	# of focus groups	# of interviews
Australia	89.2%	91	13.0	56	62.9	78.0	100.0	100.0	100.0	98.9	2	
Bangladesh	97.0%	64	16.0	57	89.1	98.4	98.4	98.4	93.8	79.7	3	
Brazil*		81	40.5	59	76.6	76.5	90.1	90.1	84.0	86.4	1	
Canada	17.6%	106	6.6	86	82.7	96.2	100.0	100.0	97.2	90.6		69
China	84.9%	213	71.0	153	77.3	90.1	87.3	87.3	85.4	84.5	3	
Hong Kong	31.6%	89	22.3	88	86.4	100.0	100.0	100.0	100.0	100.0	1	
Indonesia - Phase II*		101	6.7	17	17.3	98.0	97.0	97.0	81.2	88.1	0	
Indonesia - Phase III*		58	6.4	36	65.5	74.1	93.1	93.1	60.3	70.7	9	
Japan	43.7%	111	10.1	101	91.0	96.4	100.0	100.0	95.5	98.2	7	
Korea Republic†*		45	4.1			93.3	100.0	97.8	91.1	91.1	0	
Malaysia	70.0%	135	5.6	82	64.1	100.0	97.8	97.8	96.3	96.3	3	
Papua New Guinea‡	62.9%	100	7.7	83	85.6	100.0	100.0	100.0	95.0	98.0	20	
South Africa*		88	12.6	77	89.5	96.6	97.7	97.7	97.7	100.0	3	
Spain	28.0%	85	10.6	77	96.3	97.6	91.8	91.8	84.7	87.1	0	
Sri Lanka	49.1%	105	13.1	99	95.2	100.0	100.0	100.0	99.0	100.0	0	
Sweden**		100	8.3	72	75.0	98.0	100.0	100.0	99.0	98.0	1	
Vietnam	42.1%	137	34.3	112	83.6	91.2	98.5	98.5	95.6	95.6	1	
Zimbabwe†	56.1%	82	16.4			90.2	95.1	95.1	90.2	92.7	0	
India*		52	52	42	80.8	98.1	100.0	100.0	98.1	100.0		50
Pakistan*		24	12.0	19	82.6	100.0	95.8	95.8	79.2	79.2	0	

*The response rate could not be calculated in these countries as the denominator was unknown.
†Only the activPAL was pilot tested in these countries.
‡Data collected at the village level.
ECEC, Early Childhood Education and Care; EYT, Early Years Toolbox.

areas. The mean absolute difference in the proportion between rural and urban was 9.6%.

The power calculation is based on achieving 80% power and a 5% significance level for each country and assuming a rate of 21% of meeting all three guidelines and detecting a difference of 9.6% in either direction (two-sided) between urban and rural and based on an equal allocation to both rural and urban settings. This provides an effect size of 0.23 (small effect),[41] and results in a sample size of n=558 per country.

When assuming a response rate of 76% (based on average response rate in the 16 pilot studies), the required sample size increases to n=734. The sampling of the main study will be partly based on cluster sampling (usually childcare centres). The intra-class correlation (ICC) was estimated for each country, however, due to low pilot sample sizes in each country; the country-specific ICC estimates vary widely and are unreliable. Instead, we combined countries and estimated the ICC after controlling for country-specific effects. The resulting ICC estimate was zero. However, a zero ICC might be too optimistic (resulting in smaller sample size) for the main study, possibly resulting in too low power, if the ICC is indeed positive in the main study. To be conservative, we used an ICC estimate of 0.022 from the PATH study.[42] Taking this value and assuming data to be collected on 20 children (on average) per child care centre when 25 are recruited (on average), the sample size of n=735 is further increased to approximately n=1000. This sample size is also sufficiently large to have a margin of error of at most 5% for a 95% CI for the proportion of meeting all three guidelines for each country and for both rural and urban populations when centred around 21%.

Ethics and dissemination

Ethics approval

The overarching protocols for the pilot study (2018/044) and the main study (2019/378) have been approved by the UOW, Australia, Human Research Ethics Committee. The protocol is also approved in each country by the ethics committees at the participating institutions of each CI, as applicable (see online supplemental table 4). In addition, approval is sought from any government departments or organisations who oversee relevant settings in the different countries. Participant information sheets, consent forms and questionnaires are translated and back translated, as necessary, into the local language of each country following approved procedures of the local institutions. Parental consent is obtained for all participating children.

Quality assurance of data collection, storage and management

This component of the project has been supported by the Australian Health Services Research Institute at the UOW. A comprehensive *Research Data Management Plan* that sets out the principles and protocols governing the management, access, use and dissemination of the data has been developed. The data are securely stored in databases on password-protected servers at the UOW. All participating countries retain ownership of their data. The terms of collaboration are detailed in a Collaboration Agreement that is entered into between the UOW and the participating institutions of each CI. This collaboration agreement also details intellectual property issues, data use, confidentiality, privacy, loaning of equipment and the roles and responsibilities of each party. The agreement is reviewed by each country's legal representative and executed by both the participating country's authorised representative and the UOW authorised representative, prior to training in each country.

Global impact of SUNRISE

As the first-known international study of movement behaviours in the early years, SUNRISE will make a significant contribution to our understanding of the physical activity, sedentary behaviour and sleep patterns of preschool aged children. Further, SUNRISE will investigate if these behaviours differ by gender, parental education level, urban/rural location and among countries of differing human and economic development, and how these compare to current global movement behaviour guidelines. The study will also enable analysis of associations between movement behaviours and health and developmental indicators and provide evidence on potential correlates of movement behaviours among young children.

A considerable strength of the study is the breadth of the resulting data set. SUNRISE data will be collected in urban and rural settings in 39 countries, from every WHO region, with up to 60% of participating countries being of low-income or middle-income, resulting in a truly unique data set. A further strength of the study is the extensive pilot testing of the protocol (as described in this article) which has resulted in a scientifically robust, culturally appropriate, feasible, standardised protocol. The strong data management and capacity building elements incorporated into the design of the study are a further strength.

In conclusion, the results to be obtained by SUNRISE, particularly on the correlates of movement behaviours, have the potential to inform the development of future interventions to improve the movement behaviours in culturally specific ways across a diverse range of settings. The collaborative international network of researchers and practitioners brought together by this study will be instrumental in driving this important agenda further and will no doubt make considerable contributions to ensuring that young children reach their full developmental potential.

Author affiliations
[1]Early Start, School of Health and Society, Faculty of the Arts, Social Sciences and Humanities, University of Wollongong, Wollongong, New South Wales, Australia
[2]Physical Activity for Health, University of Strathclyde, Glasgow, UK
[3]Children's Hospital of Eastern Ontario Research Institute, Ottawa, Ontario, Canada
[4]MRC-Wits DPHRU, University of the Witwatersrand, Johannesburg-Braamfontein, South Africa

[5]Unité Mixte de Recherche Nutrition et Alimentation, Regional Designated Center of Nutrition Associated with AFRA/IAEA, CNESTEN-Université Ibn Tofail URAC39, Rabat, Morocco
[6]Universidade de Sao Paulo Escola de Artes Ciencias e Humanidades, Sao Paulo, Brazil
[7]Faculty of Business and Law, Australian Health Services Research Institute, University of Wollongong, Wollongong, New South Wales, Australia
[8]Department of Early Childhood Development, Beijing Municipal Key Laboratory of Child Development and Nutriomics, Capital Institute of Pediatrics, Beijing, China
[9]Pennington Biomedical Research Center, Baton Rouge, Louisiana, USA
[10]Vadu Rural Health Program, KEM Hospital Pune Research Centre, Pune, India
[11]Population Health and Demography Unit, PNG Institute of Medical Research, Goroka, Papua New Guinea
[12]National Institute for Applied Statistics Research Australia, School of Mathematics and Applied Statistics, Faculty of Engineering and Information Sciences, University of Wollongong, Wollongong, New South Wales, Australia
[13]Department for Prevention of Non-Communicable Diseases, WHO, Geneve, Switzerland
[14]Early Start, Faculty of the Arts, Social Sciences and Humanities, University of Wollongong, Wollongong, New South Wales, Australia
[15]Hiwot Fana Specialized University Hospital, Harar, Ethiopia
[16]Department of Physical Education, Sports and Recreation, Universidad de La Frontera, Temuco, Chile
[17]Precision Health Consultants (PHC Global), Karachi, Pakistan
[18]National Centre for Public Health, Mongolia Ministry of Health, Ulaanbaatar, Mongolia
[19]Department of Sports Science and Physical Education, Faculty of Education, The Chinese University of Hong Kong, Hong Kong, Hong Kong
[20]Department of Paediatrics, Faculty of Medicine, University of Colombo, Colombo, Sri Lanka
[21]National Institute of Education, Nanyang Technological University, Singapore
[22]Health Education, School of Medical Sciences, Tarbiat Modares University, Tehran, Iran
[23]Department of Sports Science and Physical Education, The Chinese University of Hong Kong, Hong Kong, Hong Kong
[24]Biomedical Research Foundation, Dhaka, Bangladesh
[25]School of Psychological Sciences and Health, University of Strathclyde, Glasgow, UK
[26]Department of Physical Activity and Healthy Lifestyles, Center for Nutrition and Health Research, National Institute of Public Health, Cuernavaca, Mexico
[27]Thailand Physical Activity Knowledge Development Centre, Institute for Population and Social Research, Mahidol University, Salaya, Thailand
[28]Korea Institute of Child Care and Education, Seoul, Republic of Korea
[29]Department of Epidemiology, Faculty of Public Health, Pham Ngoc Thach University of Medicine, Ho Chi Minh City, Viet Nam
[30]Centre of Community Education and Well-being, Faculty of Education, Universiti Kebangsaan Malaysia, Bangi, Malaysia
[31]National Medical Research Centre for Therapy and Preventive Medicine, Moscow, Russia
[32]Tanzania Food and Nutrition Centre, Dar es Salaam, Tanzania
[33]Department of Health, Medicine och Caring Sciences, Linköping University, Linkoping, Sweden
[34]Department of Biosciences and Nutrition, Karolinska Institute, Stockholm, Sweden
[35]Rehabilitation Sciences Unit, Faculty of Medicine and Health Sciences, University of Zimbabwe, Harare, Zimbabwe
[36]Centre for Social Research, University of Malawi, Zomba, Malawi
[37]Human Kinetics and Health Education, University of Lagos, Akoka, Nigeria
[38]Department of Sport Science and Clinical Biomechanics, University of Southern Denmark, Odense, Denmark
[39]Universidad de Sevilla, Sevilla, Spain
[40]Folkhalsen Research Centre, Helsinki, Finland
[41]Department of Food and Environmental Sciences, University of Helsinki, Helsinki, Finland
[42]Faculty of Business, University of Wollongong, Dubai, UAE
[43]School of Public Health and Primary Care, CMNHS, Fiji National University, Nasinu, Fiji
[44]Faculty of Sport and Health Education, Universitas Pendidikan Indonesia, Bandung, Indonesia
[45]College of Health and Welfare, J F Oberlin University, Machida, Japan
[46]Pham Ngoc Thach University of Medicine, Ho Chi Minh City, Viet Nam
[47]School of Economics, De la Salle University, Manila, Philippines
[48]Department of Sport Science, Faculty of Education, University of Botswana, Gaborone, Botswana
[49]Department of Public and Occupational Health, Amsterdam Public Health Research Institute, Amsterdam University Medical Center, Vrije Universiteit Amsterdam, Amsterdam, The Netherlands
[50]Institute of Public and Preventive Health, Augusta University, Augusta, Georgia, USA
[51]Faculty of Medicine, University of Colombo, Colombo, Sri Lanka

Twitter Nicolas Aguilar-Farias @nicolasaguilar and Nyaradzai Munambah @nyariemnambah

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ORCID iDs
Katharina E Kariippanon http://orcid.org/0000-0003-4269-682X
Anna Kontsevaya http://orcid.org/0000-0003-2062-1536

REFERENCES

1 Carson V, Lee EY, Hewitt L. Systematic review of the relationships between physical activity and health indicators in the early years (0-4 years). *BMC Public Health* 2017;17:33–63.
2 Lea AJ, Tung J, Archie EA, *et al*. Bridging research in evolution and human health. *Evol Med Public Heal* 2017;2017:162–75.
3 Poitras VJ, Gray CE, Janssen X, *et al*. Systematic review of the relationships between sedentary behaviour and health indicators in the early years (0–4 years). *BMC Public Health* 2017;17.
4 Rollo S, Antsygina O, Tremblay MS. The whole day matters: understanding 24-hour movement guideline adherence and relationships with health indicators across the lifespan. *J Sport Health Sci* 2020;9:493–510.
5 UNICEF. *The State of the World's children 2019. Children,* food and nutrition: growing well in a changing World 2019.
6 Voce A. Cities alive: designing for urban Childhoods. *Child Youth Environ* 2018;28:78.
7 Chaput J-P, Gray CE, Poitras VJ, *et al*. Systematic review of the relationships between sleep duration and health indicators in the early years (0–4 years). *BMC Public Health* 2017;17.
8 World Health Organization [WHO]. WHO guidelines on physical activity, sedentary behaviour for children under 5 years of age, 2019. Available: http://www.who.int/iris/handle/10665/311664
9 Tremblay MS. Introducing 24-hour movement guidelines for the early years: a new paradigm gaining momentum. *J Phys Act Health* 2020;17:92–5.
10 Tremblay MS, Carson V, Chaput J-P, *et al*. Canadian 24-hour movement guidelines for children and youth: an integration of physical activity, sedentary behaviour, and sleep. *Appl Physiol Nutr Metab* 2016;41:S311–27.
11 Okely AD, Ghersi D, Hesketh KD, *et al*. A collaborative approach to adopting/adapting guidelines - The Australian 24-Hour Movement Guidelines for the early years (Birth to 5 years): an integration of physical activity, sedentary behavior, and sleep. *BMC Public Health* 2017;17:869.
12 Monasta L, Batty GD, Cattaneo A, *et al*. Early-Life determinants of overweight and obesity: a review of systematic reviews. *Obes Rev* 2010;11:695–708.
13 NCD Risk Factor Collaboration (NCD-RisC). Height and body-mass index trajectories of school-aged children and adolescents from 1985 to 2019 in 200 countries and territories: a pooled analysis of 2181 population-based studies with 65 million participants. *Lancet* 2020;396:1511–24.
14 UNICEF. The State of the World's Children 2017. Children in a Digital World 2017.
15 Brockmann PE, Diaz B, Damiani F, *et al*. Impact of television on the quality of sleep in preschool children. *Sleep Med* 2016;20:140–4.
16 Clark H, Coll-Seck AM, Banerjee A, *et al*. A future for the world's children? A WHO–UNICEF–Lancet Commission. *The Lancet* 2020;395:605–58.
17 de Lucena Martins CM, Lemos LFGBP, de Souza Filho AN, *et al*. Adherence to 24-hour movement guidelines in low-income Brazilian preschoolers and associations with demographic correlates. *Am J Hum Biol* 2021;33:1–12.
18 Guan H, Zhang Z, Wang B, *et al*. Proportion of kindergarten children meeting the who guidelines on physical activity, sedentary behaviour and sleep and associations with adiposity in urban Beijing. *BMC Pediatr* 2020;20:1–9.
19 Okely AD, Veldman SL, de Rosnay M. Relationships between motor skill delay and executive functions in vulnerable children aged 3-5 years. *North Am Soc Study Psychol Sport Phys Act* 2017;39:S34.
20 Wei QW, Zhang JX, Scherpbier RW, *et al*. High prevalence of developmental delay among children under three years of age in poverty-stricken areas of China. *Public Health* 2015;129:1610–7.
21 Veldman SL, Jones RA, Okely A. Prevalence and risk factors of gross motor delay in Pre-schoolers from low-income communities. *J Pediatr* 2020;56:571–6.
22 Bello AI, Quartey JNA, Appiah LA. Screening for developmental delay among children attending a rural community welfare clinic in Ghana. *BMC Pediatr* 2013;13:119.
23 Bronfenbrenner U. *Readings on the development of children. In: ecological models of human development*. New York: Freeman, 1993: 37–43.
24 United Nations - Department of Economic and Social Affairs Population Division. World urbanization prospects 2014.
25 Katzmarzyk PT, Barreira TV, Broyles ST, *et al*. The International study of childhood obesity, lifestyle and the environment (ISCOLE): design and methods. *BMC Public Health* 2013;13:900.
26 Teo K, Chow CK, Vaz M, *et al*. The prospective urban rural epidemiology (pure) study: examining the impact of societal influences on chronic noncommunicable diseases in low-, middle-, and high-income countries. *Am Heart J* 2009;158:1–7.
27 Taylor RW, Haszard JJ, Meredith-Jones KA, *et al*. 24-H movement behaviors from infancy to preschool: cross-sectional and longitudinal relationships with body composition and bone health. *Int J Behav Nutr Phys Act* 2018;15:1–14.
28 Janssen X, Cliff DP, Reilly JJ, *et al*. Predictive validity and classification accuracy of ActiGraph energy expenditure equations and cut-points in young children. *PLoS One* 2013;8:e79124.
29 Smith C, Galland B, Taylor R, *et al*. ActiGraph GT3X+ and Actical wrist and hip worn Accelerometers for sleep and wake indices in young children using an automated algorithm: validation with polysomnography. *Front Psychiatry* 2019;10:1–12.
30 World Health Organization [WHO]. Training course on child growth assessment 2008.
31 Reuben DB, Magasi S, McCreath HE, *et al*. Motor assessment using the NIH Toolbox. *Neurology* 2013;80:S65–75. 11.
32 Clark JE, Damiano DL, Newell KM. Justification for and proposed assessment of motor function. For the National Children's study. *Unpubl Work Prod Doc* 2014.
33 Ulrich D. *Test of gross motor development 2: examiner's manual*. 2nd ed. Austin, TX: PRO-ED, 2000.
34 Ulrich D. *The test of gross motor development –Third Edition (TGMD-3)*. 3rd ed. Austin, TX: PRO-ED, 2019.
35 Howard SJ, Melhuish E. An early years toolbox for assessing early executive function, language, self-regulation, and social development: validity, reliability, and preliminary norms. *J Psychoeduc Assess* 2017;35:255–75.
36 UNICEF & WHO. Indicators for assessing infant and young child feeding practices. World Heal Organ; WHA55 A55/:19, 2008. Available: http://apps.who.int/iris/bitstream/handle/10665/44306/9789241599290_eng.pdf?sequence=1%0Ahttp://whqlibdoc.who.int/publications/2008/9789241596664_eng.pdf%5Cnhttp://www.unicef.org/programme/breastfeeding/innocenti.htm%5Cnhttp://innocenti15.net/declaration
37 Coates J, Swindale A, Bilinsky P. HFIAS for measurement of food access indicator guide. *J Chem Inf Model* 2013;53:1689–99.
38 World Health Organisation. The who stepwise approach to non-communicable disease risk factor surveillance (steps), 2011. Available: http://www.searo.who.int/entity/noncommunicable_diseases/data/mmr_2009_steps_survey_report.pdf
39 Harris PA, Taylor R, Minor BL, *et al*. The REDCap Consortium: building an international community of software platform partners. *J Biomed Inform* 2019;95:103208.
40 Harris PA, Taylor R, Thielke R, *et al*. Research electronic data capture (REDCap)--a metadata-driven methodology and workflow process for providing translational research informatics support. *J Biomed Inform* 2009;42:377–81.
41 Cohen J. *Statistical power analysis for the behavioral sciences*. 2nd Ed. New York: Lawrence Erlbaum, 1988.
42 Cliff DP, McNeill J, Vella SA, *et al*. Adherence to 24-hour movement guidelines for the early years and associations with social-cognitive development among Australian preschool children. *BMC Public Health* 2017;17:857.
43 Brakenridge CL, Fjeldsoe BS, Young DC, *et al*. Evaluating the effectiveness of organisational-level strategies with or without an activity tracker to reduce office workers' sitting time: a cluster-randomised trial. *Int J Behav Nutr Phys Act* 2016;13:115.
44 Headley S, Hutchinson J, Wooley S, *et al*. Subjective and objective assessment of sedentary behavior among College employees. *BMC Public Health* 2018;18:768.

Appendix B: Report for the SUNRISE Malawi dissemination and impact activities

Early Childhood Physical Activity, Screen Time, and Sleep in Malawi: Impact Activities from Current Research and Co-creation of Future Research Plans with Stakeholders Across Malawi

ISPF/SFC University of Strathclyde
Grant Report 2024

December 2024

Foreword

Professor John J. Reilly, principal investigator for the ISPF/SFC and Sir Halley Stewart Trust grants john.j.reilly@strath.ac.uk

This report summarises Knowledge Exchange (KE) work carried out during 2024 involving a partnership between the University of Strathclyde (Department of Psychological Sciences and Health) and University of Malawi (Centre for Social Research). The KE activity was funded by an International Science Partnership Fund/Scottish Funding Council grant and depended on the excellent work in Malawi carried out by Tawonga Mwase-Vuma and Janine Kayange.

It is now well established –e.g. in World Health Organisation (WHO) guidelines 2019– that physical activity, screen time and sleep have important effects on health and development in early childhood and beyond. Emerging research evidence gives cause for concern that young children globally do not get sufficient physical activity, spend too much time in front of screens and get insufficient sleep. The extent to which these problems exist in sub-Saharan Africa was unclear, and so a programme of research starting in 2021, funded initially by the Sir Halley Stewart Trust, began to investigate this topic in Malawi, a partnership between the University of Strathclyde and University of Malawi.

The KE work summarised in this report involved dissemination across Malawi of both our research work and the WHO Guidelines on Physical Activity, Sedentary Behaviour and Sleep in the Under 5's. We also used the dissemination activities to work with stakeholders across Malawi in order to (a) plan how to increase future impact of the research, and future impact of the WHO Guidelines and (b) co-create future research priorities. This report includes an executive summary followed by a more detailed account of the KE work in 2024 and future plans for KE and research. For further information please contact me (john.j.reilly@strath.ac.uk) or Tawonga Mwase-Vuma (tmwase-vuma@unima.ac.mw; taomwase@gmail.com).

Executive Summary

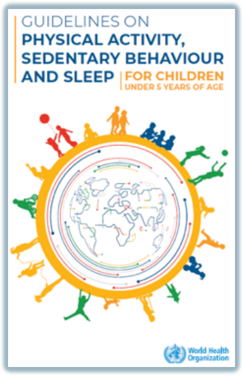
Physical activity, screen time and sleep, the ’24-hour movement behaviours’, have a significant influence on child health and development in the early years. Early childhood development (ECD) has been referred to as the ‘foundation of sustainable development’, but poverty and stunting means that many children in sub-Saharan Africa do not reach their developmental potential. Evidence based guidelines from the World Health Organisation (WHO) in 2019 recommended that-for optimal health and development, 3-4 year olds should spend at least 3 hours per day in physical activity, no more than 1 hour per day watching screens, not to be restrained for more than 1 hour at a time (e.g., in a stroller, pram, car seat, high chair, or wrapped on the back of an adult), and have at least 10 to 13 hours of good quality sleep per day.

Economic development, urbanisation and an increasingly westernised lifestyle (the ‘physical activity transition’[1]) in many low-and-middle-income countries is leading to levels of the movement behaviours which do not meet the WHO 2019 guidelines. Three grant-funded studies in Malawi from 2021 have been examining these issues in 3-4 year olds in urban and rural Malawi. This research has shown that physical activity levels of young children remain high, especially in rural settings, but only a minority of children in urban areas meet the screen time guideline- the physical activity transition appears to be underway in urban Malawi.

The ISPF/SFC KE grant work in 2024 involved workshops with a range of stakeholders in Malawi: families, education practitioners and policymakers, health and welfare practitioners and policymakers, non-governmental organisations (NGOs), and academia. The workshops operated at local level (in and around Zomba in southern Malawi, where the research took place); regional level (in Zomba district and city councils and eastern region of Malawi); and national level. Workshops disseminated our research findings and the WHO Guidelines. Following the dissemination workshops face to face co-creation workshops were held with the same stakeholders to identify priority topics for future research and KE.

The workshops showed that the movement behaviours in early childhood are considered important and the WHO 2019 Guidelines should be known and used more widely across Malawi. The Co-creation workshops identified a concern about screen time of children in urban settings and suggested that interventions which focus on screen time/physical activity/sleep should be developed. Stakeholders prioritised (a) repeating the research in the next 5-10 years to examine lifestyle changes of children as Malawi undergoes economic development and (b) following up the children who took part in the research when they are in primary school to show how the movement behaviours change as children get older –there was a concern that physical activity/screen time/sleep would all get worse as children get older. Stakeholders prioritised future KE work to increase awareness and use of the WHO 2019 Guidelines across Malawi. Discussions have just started with WHO Geneva about supporting a campaign to disseminate the WHO 2019 Guidelines in Malawi (a future KE project). In addition, two outline research grant applications have been developed, with the aim of applying for funding in 2025.

Introduction

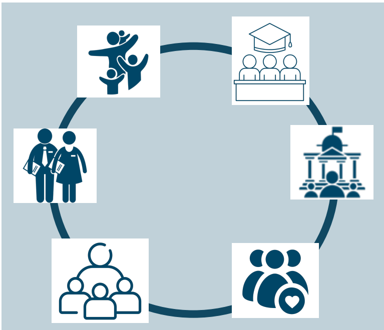


The WHO published the first global guidance for physical activity, screen time, and sleep (24-hour movement behaviours) in the under 5's in 2019.[2] These behaviours influence early childhood development including cognitive development and have long-lasting effects on physical and mental health. Despite the publication of these guidelines over five years ago, there is limited evidence on adherence to these guidelines particularly from low- and middle-income countries. The SUNRISE international study of 24-hour movement behaviours in the early years was established to address this gap by examining the prevalence and determining the correlates of meeting the 24-hour movement behaviour guidelines in 3–4-year-old children.[3] The study is coordinated by the University of Wollongong in Australia. There are currently over 60 countries globally that are actively participating in the study, including Malawi (https://sunrise-study.com).

The Malawi study, hereafter "SUNRISE Malawi", is jointly being implemented by the University of Strathclyde (led by Prof John J. Reilly who was a member of the WHO 2019 guideline development group) and the Centre for Social Research at the University of Malawi (led by Tawonga Mwase-Vuma as a Research Associate and completing his PhD at Strathclyde). Prof Reilly and Dr Xanne Janssen received a grant from the Sir Halley Stewart Trust (October 2021-October 2024) to lead the SUNRISE Malawi as PI and Co-I, respectively. Data collection for the study was conducted between February 2022 and May 2023, and included 417 children and their caregivers.

Two subsequent large grants from the Canadian Institutes for Health Research (CIHR; Reilly Co-I, Mwase-Vuma local PI; 2022-25 and 2023-25) have extended the research work and created a solid foundation for future research and impact. However, these grants did not have resource for (a) substantial impact activities in Malawi and (b) co-creation of future research with stakeholders in Malawi. Accordingly, a grant from the University of Strathclyde/Scottish Funding Council/ International Science Partnerships Fund Scheme expanded on the dissemination and impact activities at the community, regional, and national levels in Malawi as well as the co-creation of future research and impact plans with stakeholders. The activities were organised in January and February 2024 and held in April and May 2024 and involved various stakeholders across all three levels.

Community level stakeholders included families, local community leaders, and educators from childcare centres. Regional stakeholders included officials from the local government responsible early childhood education and development, parents, educators, and representatives from non-governmental organisations. National stakeholders included academics from public universities and private research institutions, representatives from NGOs, and policymakers from the ministries of education, health, and gender and community development. This report highlights the insights and feedback from the dissemination and impact activities.



Objectives

This KE grant set out to:

a. Conduct impact activities with relevant stakeholders at the local community, regional, and national level in Malawi.
b. Co-create plans with the same stakeholders for the research and impact activities which should follow the current work.

Impact activities

Impact activities involved holding dissemination meetings with stakeholders at community, district and national level. The SUNRISE Malawi research found that most young children in Malawi currently get sufficient physical activity, sufficient sleep, and avoid excessive screen time but around 40% do not meet all three guidelines combined, and screen time typically exceeds the WHO guideline in urban areas (**Figure 1**).

These findings were shared with all the main impact beneficiaries, including families, local practitioners in education and health, and national policymakers in education and health. At the community level, the findings were translated and communicated in Chichewa, a local language widely spoken in Malawi. The meetings were held in April and May 2024, as detailed in the sections below.

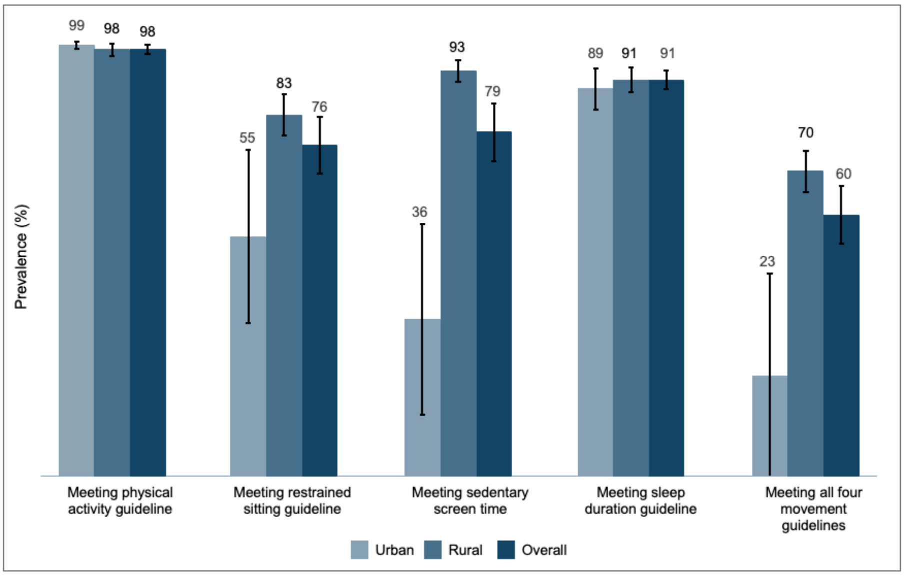


Figure 1 – Proportion of Malawian 3-4 year olds meeting the WHO guidelines
Notes: Each bar represents the estimated proportion of meeting the guidelines, and the vertical lines extending from each bar indicate the corresponding upper and lower levels of the 95% confidence intervals.

Local dissemination

Three local dissemination meetings were held at the community level on 24th, 25th and 27th April 2024, and brought together a total of 60 parents/caregivers, most of whom participated in the study together with their eligible child. The meetings also included staff from nine of the 24 early childhood education and care centres that participated in the study. Meeting venues for all the three meetings were purposively located to accommodate parents/caregivers from more than one centre as well as to ensure disseminating the findings to both rural and urban settings. Two meetings in separate venues were held in a rural setting on 24th and 25th April 2024. While in the urban setting, one meeting was held on the 27th of April 2024.

The research team presented the study findings, which included the background to the study, its objectives and the findings for the overall sample. The presentation focused on findings on physical activities, sedentary behaviours (restrained sitting and screen time), and sleep duration among 3–4 year olds in Malawi. During the presentation, the presenter emphasised the significance of adhering to the WHO 24-hour movement behaviour guidelines for children's health and development. In addition, the presenter highlighted the implications of the country's economic transformation as envisioned in the Malawi Vision 2063[4] on the observed high levels of meeting the WHO guidelines. Below we provide highlights from discussions held with stakeholders during community-level dissemination meetings, separately for the rural and urban settings.

Rural Settings

A Q&A section took place shortly after the presentation. During the discussion, participants reflected on the positive impacts of physical activity, sedentary behaviour and sleep on children's health and development noting that the findings resonated with observations in their respective homes and communities. Emphasising the importance of maintaining and enhancing these behaviours in children, they proposed practical strategies to promote and sustain healthy levels of the behaviours (**Textbox 1**).

Furthermore, participants raised concerns regarding lower levels of meeting the restrained sitting time among boys compared to girls. This was attributed to the differing developmental patterns and parenting approaches. For example, participants noted that boys are often perceived as 'troublesome' and would demand to be to be carried most times, hence leading parents especially in rural areas to carry or restrain them (i.e., at the back) for longer duration unlike girls. Additionally, girls tend to grow faster and become independent earlier than boys, hence influencing different parental practices between them.

QUOTE

Boys are indeed more likely to be sedentary than girls because they are seen as more demanding. They want to explore things, as a result their parents restrict them by wrapping them on their backs or giving them a phone as a distraction.

– Caregiver, Rural

During the meeting, participants acknowledged potential challenges following advancement in living standards in Malawi leading to reduced physical activity among children. As such, they recommended advocacy initiatives to promote physical activities among children, primarily focusing on parental engagement (**Textbox 2**):

Textbox 1: Proposed strategies to promote and sustain healthy behaviours

- Encouraging physical activities among children by providing *opportunities for structured physical activities and outdoor play*.
- *Providing toys* to promote activeness.
- Regulating *sleep schedules*.
- Allowing ample *time for rest* and play.
- Government to *establish playgrounds and recreational facilities* to promote physical activity at ECEC centres.

Textbox 2: Proposed advocacy strategies

- Educating parents and caregivers on the importance of more physical activity, reduced sedentary screen time, and increased sleep duration as well as emphasising the benefits of these movement behaviours for children's growth and development.
- Encouraging parents to actively engage their children in physical activities as well as to limit their child's screen time and set sleep times to ensure longer sleep duration.

Urban Settings

After the presentation, participants discussed the findings and possible ways to address the disparities observed in meeting the WHO guidelines for children, particularly focusing on sex disparities and urban-rural differences.

Sex disparities: Participants concurred with the finding that boys were more likely to be restrained by parents (e.g., by putting them at the back) as they are considered troublesome. They also explained that girls were 'disciplined' and 'obedient' unlike boys.

Urban- Rural differences: Participants concurred with the finding that most children in the urban setting do not meet the screen time guideline. They stated that the finding aligns with their experience as urban children have greater access to electronic screen devices compared to their rural counterparts.

QUOTE

In urban setting many children are likely to watch TV after school and when they are free. As such, they spend much of their time watching TV. While in rural areas access to TV is a challenge hence children spend the day playing outside the house.

– Caregiver, Urban

In addition, participants acknowledged the potential decline in physical activity among children amidst the country's envisioned socioeconomic development. Coupled with the reported disparities in meeting the WHO guidelines by sex and residential settings, participants proposed a number of actionable strategies involving different stakeholders to advocate and raise awareness about the global guidelines (**Textbox 3**). Participants also discussed strategies to promote and sustain the observed healthy levels of movement behaviours in young children (**Textbox 4**).

Textbox 3: Proposed strategies to promote and sustain healthy behaviours in children

- *Incorporating movement behaviour guidelines in the teacher training curriculum for basic education* (ECD and primary school). Participants argued that teachers would be key in teaching children the importance of being more active and involving them in various activities as part of the school curriculum.
- *The government should establish more ECD centres with playgrounds* and make it compulsory for every child to attend early childhood education before primary school.
- *Creating environment at ECD centres that promote outdoor play* and reduce sedentary time, e.g., providing balls, used tyres, skipping ropes
- Local leaders in collaboration with relevant local government ministries and departments to *enforce laws to promote ECEC attendance* so that children are exposed to these healthy behaviours.

Textbox 4: Proposed advocacy and awareness strategies for the WHO guidelines

- *Orienting community health workers (CHWs) and personnel from NGOs and CSOs on the 24-hour movement behaviours* for young children to help spread information about the behaviours.
- *Engaging CHWs in conducting advocacy and awareness raising sessions* about the movement behaviour guidelines and findings from the present study. CHWs should leverage the health education talks they conduct at antenatal care service to further spread the message.
- *Peer-to-peer advocacy* among neighbours/families and community groups, e.g. *Gowelo* (a place where men always meet to catch up or play board games) and village savings and loans groups. Participants emphasised the importance of involving both parents, as appropriate, because they are both primary carers for young children.
- *Engaging parents more especially fathers through meetings and community forums* as well as continued spread of information about the movement behaviours through SMSs, social media (e.g., utilising the pages of social media influencers), TV, and radios.
- Religious leaders should *integrate benefits of the movement behaviours into sermons*, e.g., at Sunday and Sabbath schools.
- Research institutions urged to *utilize the findings to advocate for policy changes*, programming, and ECE curriculum enhancement.
- Research institutions should utilise the findings and help in conducting information sessions and awareness campaigns healthy movement behaviours among children.

Regional dissemination

The meeting took place on 26th April 2024 with an attendance of 20 stakeholders, including educators (e.g., staff from early childhood education and care centres that participated in the study, including centre directors/heads and teachers), representatives from community and civil society organisations, and local government officials (e.g., officials from the district social welfare and education offices).

The research team gave a presentation about the study background, objectives, and findings. The presentation focused on findings on physical activities, sedentary behaviours (restrained sitting and screen time), and sleep duration among 3–4 year olds in Malawi. During the presentation, the presenter emphasised on the significance of adhering to the WHO 24-hour movement behaviour guidelines for children's health and development. In addition, the presenter highlighted on the implication of the country's economic transformation as envisioned in the Malawi Vision 2063[4] on the observed high levels of meeting the WHO guidelines.

After the presentation, participants reflected on the findings and discussed strategies that might ensure children attending ECECs meet the sleep guideline, including provision of nap times at the centre. The key points that emerged during the Q&A session were on the differences in meeting the guidelines among boys and girls as well as between urban and rural residents. These have been summarised below.

QUOTE

"There is need to popularize the WHO guidelines because a lot of people are not aware of them, I was not aware of them. We can say we are lucky now as most of our children are meeting the guidelines but if these guidelines are not popularized, we might be discussing something else in the future.".

– Regional stakeholder

9

Sex differences in meeting the restrained sitting guideline: Following the presentation, participants discussed the variations in meeting the restrained guideline, as well as between urban and rural residential settings. Participants explained that the finding that more girls meet the restrained time guideline than boys would be due to the differing parenting approaches, as boys are ‘troublesome’ and often regarded as more demanding than girls, who are considered cooperative and less demanding. As a result, parents/caregivers resort to restraining boys by wrapping them on their back. Additionally, participants explained that the lower levels of meeting the restrained sitting guideline among boys could be because they tend to spend more time travelling with their fathers or other male adult household members in households that own a car, motorbike, or bicycle, unlike girls.

Urban-rural difference in meeting the screen time guideline: Participants concurred with the finding and explained that the difference could be due to limited access to electricity and screens in the rural settings unlike in the urban settings, hence urban children spend more time using electronic screen devices. Additionally, participants explained that limited access to electronic screens in rural settings means rural children tend to sleep earlier than their urban counterparts. Participants further explained that most rural children tend to spend the entire day outdoors playing due to their limited access to electronic screen devices at home. In contrast, they explained that most urban children have limited outdoor playtime due availability of electronic screen devices at home or parents/caregivers restricting them from outdoor play away from their households to reduce any security threats.

Urban-rural differences in meeting the sleep duration guideline: The question about daytime naps was raised, and it was observed that urban ECEC centres provide nap times during school hours unlike their rural counterparts. Despite the difference, it was observed that most ECEC centres in both urban and rural settings operate a half day attendance (i.e., between 8 a.m. and 12 noon), which limits the provision of nap times.

Textbox 5: Summary of recommendations from regional stakeholders

- Simplify the study findings and share with ECEC centres.
- Conduct advocacy and awareness raising activities through communities and at ECEC centres.
- Engage civil society organisations, NGOs, and CHWs in advocacy and awareness raising initiatives.
- Research institutions should collaborate with NGOs when conducting trainings on the WHO guidelines.
- The government should introduce in training curriculum for primary school teachers an ECD curriculum that incorporates the WHO guidelines.

Recommendations

- Consider sharing simplified findings in ECEC centres and schools to inform activities that promote healthy behaviours among children, including physical activity and sleep (daytime naps). Sharing the findings to centres would also help to raise awareness about the importance of the 24-hour movement behaviours among centre staff and parents/caregivers.

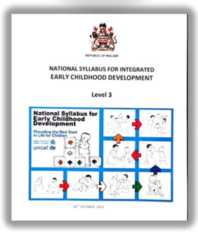
- Advocacy initiatives for families and communities to emphasise the importance of meeting the guidelines as well as the need to implement structured routines, i.e. scheduling children's activities with more time to those that promote physical activity and sleep.

Who should be advocating for the WHO movement behaviour guidelines?

Participants suggested that different stakeholders should be engaged. These include:

- Parents who have knowledge of the present research should *share the information about the 24-hour movement behaviours and the findings* to their friends and neighbours within their communities. These parents should also engage their counterparts to ensure that children engage in activities that promote adherence to the guidelines.
- ECEC centres that participated in the study and its dissemination activities should also *advocate for the WHO guidelines* and promote adherence in children.
- Research institutions (e.g., Centre for Social Research) should *engage civil society organizations (CSOs)* to help advocate for the WHO guidelines and the importance of meeting those guidelines in children.
- NGOs implementing ECD-related activities should help raise awareness about the WHO 24-hour movement behaviour guidelines, the study findings, and adherence to the guidelines.
- Community Health Workers are key in promoting healthy behaviours and preventive measures at the community level. These are the largest cadre of health care workers based at the community level. They conduct health education talks on various topics within the community and at the health facility level. Participants explained that these would help in disseminating the study findings further as well as advocating for adherence to the movement behaviour guidelines in children.

Who to conduct training in WHO movement behaviour guidelines?



- Research institutions and relevant stakeholders should *collaborate* in facilitating training on the movement behaviour guidelines and initiatives that could help to meet the guidelines.
- National government should introduce training for primary school teachers on ECD that incorporates the movement behaviour guidelines and the current evidence. Stakeholders also highlighted the need for the ECD curriculum to be streamlined in all ECEC centres across the country to help guide centre activities to ensure adherence to the WHO guidelines in young children. Some stakeholders argued that it was high time ECD curriculum focused on other aspects of childhood education beyond development of literacy and numeracy skills in young children.

How to collaborate with stakeholders in order to disseminate and increase advocacy for the WHO guidelines?

- The social welfare office of the local government council should be engaged to help identify CSOs and NGOs that focus on early childhood health and development to advocate for the WHO movement behaviour guidelines and the study findings. Participants recommended that some stakeholders working directly with ECEC centre should also be engaged and trained to help continue disseminating the study findings as well as advocating for the WHO guidelines.
- Local government (councils) through the social welfare departments should develop policies that promote ECD as well as children attending ECEC centre to learn habits that would promote healthy lifestyles and adherence to the guidelines.

National Dissemination

The meeting with national stakeholders took place on the 02nd and 3rd May 2024 with attendance of 15 various stakeholders including researchers, government policymakers, and NGOs.

The research team gave two presentations, namely: 1) the importance of movement behaviours for childhood health and development and 2) the study background, objectives, and findings. The second presentation focused on the findings on meeting the physical activity, sedentary behaviours (restrained sitting and screen time), and sleep duration guidelines among 3–4 year olds in Malawi. During this presentation, the presenter emphasised the significance of meeting the WHO 24-hour movement behaviour guidelines for children's health and development. In addition, the presenter highlighted the implications of the country's economic transformation as envisioned in the Malawi Vision 2063[4] on the observed exceptionally high levels of meeting the WHO guidelines.

After the presentation, delegates discussed the following during Q&A session.

Textbox 6: Summary of recommendations from national stakeholders

- Conduct advocacy initiatives to raise awareness of the WHO guidelines.
- Improve primary school curriculum delivery that incorporates organised periods of physical activity.
- Future research to consider additional variables, such as nutrition and cognitive development.

1. Awareness of WHO Guidelines

Participants acknowledged the importance of movement behaviours for child health. However, some participants questioned the extent to which WHO guidelines on movement behaviours are known to Malawian stakeholders. It was proposed to publish the study findings and *conduct further advocacy meetings* to disseminate the guidelines effectively. Concerns were raised regarding screen time, acknowledging its potential impact on children's health if not balanced with physical activity. This concern was raised against the background that the Ministry of Education is rolling out an education curriculum that use tablets for learners in primary school to promote early grade literacy.

QUOTE

The Ministry of Health is delighted with the implementation of the SUNRISE study. The study team has addressed a priority topic in the National Health Research Agenda II. With the improvement in socioeconomic status, improved technology and urbanization, most children are leaving a sedentary lifestyle. This has a long-term effect on their health. Therefore, understanding the movement behaviours will help the Ministry of Health to collaborate with other Ministries and Stakeholders to develop strategies that will help improve the level of activity among children.

– National stakeholder

2. Challenges in physical education

Concerns were raised on the implementation of physical education classes in schools. It was observed that such classes were not included on the timetable as often as in the past. As such, delegates suggested the need to *improve primary school curriculum delivery that incorporates organised periods of physical activity*.

Further, the existing ECD curriculum was discussed, emphasising the importance of caregiver training and curriculum alignment with childhood developmental stages. Additionally, participants highlighted the need for *future research to consider additional variables, such as nutrition and cognitive development*, in order to provide a comprehensive understanding of child health and development outcomes, including adherence to the movement behaviour guidelines.

Co-creation of future research and impact plans with stakeholders in Malawi

Malawi currently has no public health surveillance (monitoring) of early childhood physical activity as in most other low-and-middle-income countries (LMICs). Our previous study funded by the Sir Halley Stewart Trust grant established that step-counting is a valid and practical option for surveillance in LMICs.[5] The work has also shown that pre-school children living in villages have high levels of physical activity and negligible screen time, but those in town have been affected by the 'Physical Activity Transition'[1] with lower physical activity and the emergence of concerning levels of screen time (Mwase-Vuma et al., Under review at the Journal of Physical Activity and Health).

Stakeholders at all levels identified and prioritised different ideas for future research, which are listed below in order of their priority.

1. Developing an intervention for the less active children living in the urban settings to help address the identified issues (e.g., high levels of screen time) to inform policy effort. The intervention should include structured activities that encompass fun time to make activities attractive, interesting, and sustainable. Examples of interventions include implementing organised sporting activities in schools to promote active healthy habits, introducing sporting activities in pre-schools, and revising the ECD curriculum to include activities that promote meeting the guidelines. Stakeholders emphasized the importance of involving relevant ministries, councils, and research institutions in intervention efforts.
2. Turning the current cross-sectional studies into longitudinal studies. These would be useful for tracking movement behavioural changes in participants over time to inform evidence-based interventions. The studies could have a 5 or 10 year follow up period.
3. Developing a repeated cross-sectional study with larger and representative sample to understand the physical activity transition[1] in Malawi and inform evidence-based interventions to delay the transition. The studies could have a 5 or 10 year follow up period.
4. Developing a national survey for physical activity, screen time, and sleep to assess the levels and help monitor adherence to the movement behaviour guidelines.
5. Other research questions from Malawi stakeholders included developing research projects that include PGR opportunities to build capacity in this field as well as projects that ensure equal participation of children from both urban and rural settings and those with disabilities as well as educational and cognitive outcomes.

An outline proposal was developed based on the above research areas. Specifically, the proposed future research will focus on conducting three studies, namely longitudinal, repeated cross-sectional, and qualitative studies. Funding for the proposed research will be sought in 2025.

Stakeholders also agreed that future KE efforts to disseminate and embed the WHO Guidelines in Malawi should be the highest KE priority in future.

Stakeholder mapping

Delegates at the regional and national dissemination workshops were asked to identify stakeholders who would be involved in future research studies and future KE work. They include the following:

- Ministry of Health, which is responsible for ensuring improved health of all Malawians, including children.
- Ministry of Gender, Community Development, and Social Welfare, which is responsible for early childhood education and development in Malawi.
- Ministry of Education, which is responsible for providing education and monitoring education standards in Malawi.
- Malawi Institute of Education, which is responsible for curriculum development and review across all education sectors in Malawi.
- Ministry of Local Government, Culture, and Unity (MLGCU) which oversees implementation of government policies and services across various sectors within local authorities, such as at the city and district councils, in Malawi. The Ministry is also responsible for accelerating rural development and improving living standards of rural populations in the country.
- National Planning Commission, which coordinates and oversees implementation of the Malawi Vision 2063 that will see the country transforming into an upper-middle-income economy.[3]
- Department of Urban Development, which is housed within the MLGCU and oversees the long-term socioeconomic and physical growth and development of cities and urban areas.
- Non-government and civil society organisations and networks.
- Development partners, such as WHO Country Office, UNICEF Malawi, etc.
- Local government authorities at the district level, including the District Commissioner, officials from health, social welfare, and early child development offices.
- Local and influential leaders, including community and religious leaders, local councillors and members of parliament.
- Community health workers and educators from ECEC centres and primary schools.

Conclusions

The WHO 24-hour movement behaviour guidelines emphasise the importance of these behaviours for children's physical and mental health, growth cognitive development, and social and emotional development.[2] SUNRISE Malawi is being implemented to provide evidence on the levels and correlates of meeting the guidelines among young children in the country. Our research was supported by three grants, initially from the Sir Halley Stewart Trust and two other more recent grants from the Canadian Institutes for Health Research (CIHR) to expand our work. These grants had limited funds for substantial impact activities. As such, a grant from the University of Strathclyde/Scottish Funding Council/ International Science Partnerships Fund Scheme expanded the dissemination and impact activities and co-creation of future research and impact plans as described above.

The main impact beneficiaries were families, local practitioners in education and health, and national policymakers in education, health, and social welfare and community development. In total, over 90 beneficiaries participated in the impact activities at community, regional, and national levels. Overall, participants expressed the view that the SUNRISE Malawi study findings are consistent with their practical experiences and proposed various strategies to sustain healthy active lifestyle among children in Malawi in future. In addition, regional and national stakeholders identified and prioritised different ideas for future research and KE and identified the stakeholders that would be key in implementing such research and KE.

References

1. Katzmarzyk PT, Mason C. The Physical Activity Transition. *J Phys Act Health*. 2009;6(3):269-280. doi:10.1123/jpah.6.3.269

2. World Health Organization. *World Health Organisation Guidelines for Physical Activity, Sedentary Behaviour, and Sleep for Children under 5 Years of Age*.; 2019. Accessed March 13, 2024. https://www.who.int/publications/i/item/9789241550536

3. Okely AD, Reilly JJ, Tremblay MS, et al. Cross-sectional examination of 24-hour movement behaviours among 3- and 4-year-old children in urban and rural settings in low-income, middle-income and high-income countries: the SUNRISE study protocol. *BMJ Open*. 2021;11(10):e049267. doi:10.1136/bmjopen-2021-049267

4. Government of Malawi. *Malawi's Vision: An Inclusively Wealthy and Self-Reliant Nation*.; 2020. Accessed March 3, 2024. https://npc.mw/wp-content/uploads/2021/02/MW2063-VISION-FINAL.pdf

5. Mwase-Vuma TW, Janssen X, Okely AD, et al. Validity of low-cost measures for global surveillance of physical activity in pre-school children: The SUNRISE validation study. *J Sci Med Sport*. 2022;25(12):1002-1007. doi:10.1016/j.jsams.2022.10.003

Acknowledgements

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Funding source: This Knowledge Exchange (KE) work was jointly carried out by the University of Strathclyde (Department of Psychological Sciences and Health) and the University of Malawi (Centre for Social Research) with funding from the International Science Partnership Fund/Scottish Funding Council grant. The SUNRISE Malawi study was implemented with funding from Sir Halley Stewart Trust. The views presented in this report are solely the responsibility of the author(s) and do not necessarily represent the views of the funding sources and the universities of Strathclyde and Malawi.

Photo credit: SUNRISE Malawi study 2024. Icons: The Noun Project.

Appendix C: SUNRISE Parent questionnaire

SUNRISE
International Study
of 24-hour movement behaviours in the early years

Office use only
Child ID: __ __ __ __ __ __ __

THE SUNRISE STUDY
INTERNATIONAL STUDY OF 24-HOUR MOVEMENT BEHAVIOURS IN THE EARLY YEARS
PARENT/CAREGIVER QUESTIONNAIRE

This questionnaire is to be administered/completed by the MAIN caregiver of the child who lives with them and is 3 or 4 years old at the time of interview. A separate questionnaire should be used for each eligible child.

MODULE OF CHILD AND CAREGIVER BACKGROUND			
1.	What is the date of birth of the child? (dd/mm/yyyy)	**2.**	If the child's date of birth is not known, how old is the child in years? (Age in completed year)
	_________/_________/_______________		…………………………………………………………
3.	Parent/caregiver's relationship to the child participating in the study?		
	☐ Mother ☐ Father ☐ Grandmother ☐ Grandfather ☐ Legal Guardian ☐ Other (please specify): …………………………………………….		
4.	What is the sex of the child?	**5.**	What is the gender of the main caregiver?
	☐ Boy ☐ Girl		☐ Male ☐ Female ☐ Other ☐ Non specific
6.	What is your (parent/caregiver) date of birth? (dd/mm/yyyy)	**7.**	If you (parent/caregiver) do not know your date of birth, how old are you (in years)?
	_________/_________/_______________		…………………………………………………………

1

8.	What is the highest level of parental/caregiver education completed by a member of your household?
	☐ No formal schooling ☐ Primary school ☐ Secondary or high school ☐ Vocational education ☐ Tertiary education ☐ Don't know/refused
9.	What is your ethnic group/racial group/cultural subgroup/cultural background? Multiple answers possible.
	☐ Asian ☐ Aboriginal/Torres Strait Islander ☐ Middle-Eastern ☐ European ☐ African ☐ Other (please specify): …………………………………………….

CORE: SEDENTARY BEHAVIOUR, SCREEN TIME AND SLEEP		
The next questions ask about your child's movement behaviours. Please report the **number of hours and minutes per day** (for all the questions). E.g. 1 hour and 30 mins		
10.	In the past week, were there any days where the 3 or 4-year-old child who is participating in this study was restrained for more than one hour at a time in a stroller, car seat, or on back or a scooter/motorbike?	
	☐ Yes ☐ No	
11.	Over a **typical weekday**, how much time does the child spend as a passenger in a motor vehicle (e.g. a car, bus, motorcycle)	…………hrs ………………..mins
12.	Over a **typical weekend day**, how much time does this child spend as a passenger in a motor vehicle (e.g., a car, bus, motorcycle)	…………hrs ………………..mins
13.	On a typical **weekday**, how much time does your child spend outside?	…………hrs ………………..mins
14.	On a typical **weekend day**, how much time does your child spend outside?	…………hrs ………………..mins
15a.	In the past three days, has the child: Gone outside the home to play (alone/with an adult/older child)?	
	☐ Yes ☐ No	
15b.	**If Yes**, where did the child go? **(tick as many as appropriate)** ☐ On the property (i.e. Garden/yard) ☐ To a friend/relative's home ☐ To a park/square or playground ☐ To a swimming pool/creek/river/dam/waterhole/beach ☐ To the street ☐ To the bush/forest/nature environment ☐ Any other not mentioned? (please specify) ………	

3

15c.	In the past three days, has the child: <u>**Not**</u> gone/been allowed to go/been taken outside to play because of **(tick as many as appropriate)**
	☐ Heat ☐ Noise or crowding ☐ Cold ☐ Garbage/rubbish ☐ Rain ☐ Social unrest ☐ Air pollution (dirty, smoky, smelly) ☐ Dangers such as crime/kidnapping ☐ Water pollution ☐ Dangers such as traffic ☐ Any other not mentioned? (please specify) …………………………………………………………………………………………………… ☐ Not relevant
16.	**On a 24-hour period in the past week**, how much time did the 3 or 4-year-old child who is participating in this study spend using any electronic screen device such as a smart phone, tablet, video game, or watch television or movies, videos on the internet while they were sitting or lying down? Please record this as accurately as you can to the nearest minute — …………hrs …………..mins
17.	How often do you use an electronic screen device to educate this child?
	☐ Never ☐ Less than once a week ☐ Once a week ☐ Most days ☐ Every day ☐ Don't know
18.	How often do you use an electronic screen device to calm down this child when he/she is upset?
	☐ Never ☐ Less than once a week ☐ Once a week ☐ Most days ☐ Every day ☐ Don't know
19.	How often do you use an electronic screen device to keep this child busy while you get things done?
	☐ Never ☐ Less than once a week ☐ Once a week ☐ Most days ☐ Every day ☐ Don't know
20.	How often do you use a smartphone to make calls, text messages, check email, watch a video during meals with the child?
	☐ Never ☐ Less than once a week ☐ Once a week ☐ Most days ☐ Every day ☐ Don't know
21.	How often do you use a smartphone to make calls, text messages, check email, watch a video during playtime with the child?

	☐ Never ☐ Less than once a week ☐ Once a week ☐ Most days ☐ Every day ☐ Don't know
22.	How often do you use a smartphone to make calls, text messages, check email, watch a video during travel time with the child?
	☐ Never ☐ Less than once a week ☐ Once a week ☐ Most days ☐ Every day ☐ Don't know
23.	How often do you use a smartphone to make calls, text messages, check email, watch a video while going for walks with the child?
	☐ Never ☐ Less than once a week ☐ Once a week ☐ Most days ☐ Every day ☐ Don't know
24.	How often do you use a smartphone to make calls, text messages, check email, watch a video during bedtime routine with the child?
	☐ Never ☐ Less than once a week ☐ Once a week ☐ Most days ☐ Every day ☐ Don't know
25a.	Does the child use electronic screen devices (e.g. TV, video game, computer, tablet or smartphone) in the 2 hours before bedtime on a daily basis? **If no, go to question 26**
	☐ Yes ☐ No ☐ Don't know
25b.	**If Yes**, how close to bedtime does the child usually use these devices?
	☐ Closer than 30 minutes before bedtime ☐ 30 mins to less than 1 hour before bedtime ☐ Between 1 and 2 hours before bedtime
26.	Does the child have electronic screen devices in the room where he/she sleeps (e.g. TV, video game, computer, tablet or smartphone)?
	☐ Yes ☐ No

27.	How many hours of sleep does this child get in a typical 24-hours day (including naps)?		…………hrs ……………….mins
28a.	Does your child nap? **If yes, go to 28b**	**28b.**	**If yes**, what time does your child nap?
	☐ Yes ☐ No		Begin time: …………………… End time: ……………………..
29a.	Does the child have a consistent bedtime?	**29b.**	Does this child have a consistent wake-up time?

5

	☐ Yes, bedtime does not vary by more than 30 minutes each day ☐ No, bedtime can vary more than 30 minutes each day		☐ Yes, wake-up time does not vary by more than 30 minutes each day ☐ No, wake-up time can vary more than 30 minutes each day
30a.	What time does your child go to bed at night?	**30b.**	What time does your child get up in the morning?
	Bed time: …………………… PM	Wake-up time: …………………… AM	
31.	On a scale of 1 to 7, with the higher number indicating higher quality, how would you rate the quality of this child's sleep? 1 would indicate very difficult to settle, wakes many times during the night for prolonged periods and is very restless (tosses and turns, throw off bedclothes) while 7 would indicate settles and drifts off to sleep with a few minutes, sleeps right through the night, and has a very sound, deep sleep)		
	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ Don't know		
32a.	In the past three days, has the child: **Not** got enough sleep?		
	☐ Yes ☐ No		
32b.	**If Yes**, was it because of: **(tick as many as appropriate)**		
	☐ Outside noise (like traffic/train/street noises) ☐ Indoor noise ☐ Too Hot ☐ Too cold ☐ Too much light coming in to the room ☐ Other (please specify)……………………………………………………………………		
33a	Does the child sleep in their own bedroom by themselves?		
	☐ Yes ☐ No		
33b.	**If No,** how many other people sleep in the same room as the child?		
	…………………Children ………………… Adults (18 years and older)		
33c.	**If No,** how many other people sleep in the same bed as the child?		
	………………Not Relevant …………………Children ………………… Adults (18 years and older)		
34.	How often is there a bedtime routine for this child (e.g., bath time, saying goodnight, storytelling, etc)?		
	☐ Never ☐ Less than once a week ☐ Once a week ☐ Most days ☐ Every day		

6

	☐ Don't know

FOOD SOURCES	
35a.	Do you ever give your child money to buy food?
	☐ Yes ☐ No
35b.	If **Yes**, on how many days per week? _______ days
36a.	Does your child take any food to the childcare centre?
	☐ Yes ☐ No
36b.	**If Yes**, which meal(s) do they typically take with them and on how many days per week?

	Once a week	Twice a week	3 times a week	4 times a week	5 or more times a week	No
Breakfast	☐	☐	☐	☐	☐	☐
Lunch	☐	☐	☐	☐	☐	☐
Dinner	☐	☐	☐	☐	☐	☐
Snacks	☐	☐	☐	☐	☐	☐

37.	Does your child have any special dietary requirements/restrictions (e.g. dairy-free food, gluten-free food)?
	☐ Yes ☐ No
37a.	If **Yes**, please specify ____
DIETARY DIVERSITY[1]	
38.	Did your child eat any of the following types of food yesterday, during the day or night?

	Yes	No	Don't know
Grains, roots and tubers (e.g. Bread, cereals, noodles, pasta, potatoes, rice)	☐	☐	☐
Legumes and nuts (e.g. Beans, peas, lentils, walnuts, or seeds)	☐	☐	☐
Dairy/milk products (e.g. Cheese, curd, custard, ice-cream, kefir, milk and yogurt. Exception of butter and sour cream)	☐	☐	☐

	Fresh foods (e.g. meat, fish, poultry and liver/organ meats)	☐	☐	☐
	Eggs	☐	☐	☐
	Vitamin-A rich fruits and vegetables (e.g. green leafy vegetables, yellow and orange inside vegetables and orange non-citrus fruits)	☐	☐	☐
	Other fruits and vegetables (e.g. Apple, banana, orange, pear)	☐	☐	☐

EATING BEHAVIOURS AT HOME	
39.	How often is the TV or an electronic screen device on during meal or snack time?
	☐ Never ☐ Rarely ☐ Once a week ☐ Most days ☐ Every day ☐ Don't know
40.	How often do you sit with your child during meals?
	☐ Never ☐ Rarely ☐ Once a week ☐ Most days ☐ Every day ☐ Don't know
41.	How often do all of the family sit together during a main meal?
	☐ Never ☐ Rarely ☐ Once a week ☐ Most days ☐ Every day ☐ Don't know
42.	How often does your child eat or drink different foods and beverages to you during meal and snack times?
	☐ Never ☐ Rarely ☐ Once a week ☐ Most days ☐ Every day ☐ Don't know
43.	How often does your child have snacks like chips, biscuits, cakes, candies, chocolate, pastries, and sweets between meals?
	☐ Never ☐ Rarely ☐ Once a week ☐ Most days ☐ Every day ☐ Don't know
44.	How often does your child drink sugary drinks (e.g. Cordials, flavoured milk, fruit juice, soda, soft drink)?
	☐ Never ☐ Rarely ☐ Once a week ☐ Most days ☐ Every day ☐ Don't know
FOOD INSECURITY	
45a.	Does your household ever run out of money to buy food?
	☐ Yes ☐ No
45b.	Do you ever cut the size of meals or skip meals because there is not enough money for food?

	☐ Yes ☐ No
45c.	Do you go to bed hungry because there is not enough money to buy food?
	☐ Yes ☐ No
46.	Comments: ____ ____ ____ ____ ____
47.	Date survey was completed: DD/MM/YYYY ______/________/____________

Appendix D: SUNRISE Centre questionnaire

SUNRISE International Study of 24-hour movement behaviours in the early years

EARLY START

UNIVERSITY OF WOLLONGONG AUSTRALIA

Centre Information Questionnaire

1.	Centre Name:	**1a.**	Centre number:
	…………………………………………………………		…………………………………………………………
2.	Data collection start date:	**3.**	Data collection end date:
	_______/_______/__________		_______/_______/__________
4.	Sector:		
	☐ Urban ☐ Rural		
5.	Total number of eligible children at the centre:		
	……		
6.	Number of eligible children at the centre that **did consent** to participate in the study		
	……		
7.	Did any children at this centre withdraw from the study after consenting?		
	☐ Yes ☐ No		
7a.	How many children withdrew from this centre after consenting?	**7b.**	Why did they withdraw?
	…………………………………………………………		…………………………………………………………
8.	Do the eligible children who are participating in the SUNRISE Study have a naptime in this centre?		
	☐ Yes ☐ No		
8a.	What time does the nap start? (24hr time in hours and minutes)	**8b.**	What time does the nap end? (24hr time in hours and minutes)
	…………………………………………………………		…………………………………………………………

1

9.	In which season are you collecting data in this centre?
	☐ Spring ☐ Summer ☐ Autumn ☐ Winter ☐ Other (please specify)……………………………………………………………………….

10.	Were there any ActiGraphs lost in this centre? If no, please go to question 11	**10a.**	How many monitors were lost in this centre?
	☐ Yes ☐ No		…………………………………………………………

10b.	What are the serial numbers of the lost UOW ActiGraphs in this centre?
	…… …… …… ……
11.	In the past three days, have the eligible children who are participating in the SUNRISE Study:

11a.	**Not** gone/been allowed to go/been taken outside to play at the because of (tick as many as appropriate)	**11b.**	**Not** got enough sleep during nap time because of (tick as many as appropriate)
	☐ Heat ☐ Cold ☐ Rain ☐ Air pollution (dirty, smoky, smelly) ☐ Noise ☐ Other, please specify: ………………………………………………………………. ☐ Not relevant		☐ Indoor noise ☐ Outdoor noise (traffic/train/street noises) ☐ Too hot ☐ Too cold ☐ Too much light coming in to the room ☐ Other, please specify: ………………………………………………………………. ☐ Not relevant

12.	What are the current COVID restrictions for the area where this centre is located?
	…… …… ……
12a.	If any restrictions, how has COVID-19 impacted the practices and activities that occur within the centre? (e.g., restricted play equipment,...)
	…… …… ……

2

13.	Does the childcare centre provide any meals or snacks? (Please tick all that applies)
	☐ Breakfast ☐ Lunch ☐ Dinner ☐ Snacks ☐ None
14.	Does the childcare centre provide a cooked meal every day?
	☐ Yes ☐ No
15.	Does the childcare centre have any rules about what food they can bring?
	☐ Yes ☐ No
15a.	If **Yes**, what are the rules?
	☐ Not permitted to bring food to the childcare centre ☐ Other rules (please specify): ____________________
16.	Any other relevant information/comments about this centre or any problems during data collection in this centre?
	…………………………………………………………… …………………………………………………………… …………………………………………………………… ……………………………………………………………

<u>Please make a screenshot each day at the main outdoor playtime or at 12PM if there is not a scheduled playtime using the Plume app and upload them into REDCap</u>

Appendix E: University of Wollongong ethics approval letter

Dear Professor Okely,

I am pleased to advise that the application detailed below has been **approved. Please note, while approval has been granted through UOW ethics, please send through the ethics approvals from the specific sites as you gain them prior to commencing data collection**.

Ethics Number:	2018/044
Approval Date:	03/04/2018
Expiry Date:	02/04/2019
Project Title:	SUNRISE
Researchers:	Okely Tony; Tremblay Mark;
Documents Approved:	UOW application for HREC approval v7 23/01/2018 Response to HREC Review of SUNRISE Pilot Study 28/3/2018 Consent form v7 23/01/2018 Participant information sheet v7 23/01/2018 Ages and Stages questionnaire v7 23/01/2018 WHO STEPS parent questionnaire V7 23/01/2018 Activity monitor instruction sheet v7 23/01/2018 Email re translation of overseas ethics approvals SUNRISE Ethics response
Documents Noted:	Ethics Approval Brazil site Ethics Approval China site

Sites:

Early Childhood Settings located in:	Principal Investigator for Site
Canada	Mark Tremblay
China	Guan Hongyan
South Africa	Catherine Draper
Brazil	Alex Florindos
Papua New Guinea	Bang Pham Nguyen

The HREC has reviewed the research proposal for compliance with the *National Statement on Ethical Conduct in Human Research* and approval of this project is conditional upon your continuing compliance with this document. Compliance is monitored through progress reports; the HREC may also undertake physical monitoring of research.

Approval is granted for a twelve month period; extension of this approval will be considered on receipt of a progress report **prior to the expiry date**. Extension of approval requires:

- The submission of an annual progress report and a final report on completion of your project.
- Approval by the HREC of any proposed changes to the protocol or investigators.
- Immediate report of serious or unexpected adverse effects on participants.
- Immediate report of unforeseen events that might affect the continued acceptability of the project.

If you have any queries regarding the HREC review process or your ongoing approval please contact the Ethics Unit on 4221 3386 or email rso-ethics@uow.edu.au.

Yours sincerely,

Emma Barkus

Associate Professor Emma Barkus,
Chair, UOW & ISLHD Social Sciences Human Research Ethics Committee

The University of Wollongong and Illawarra and Shoalhaven Local Health District Social Sciences HREC is constituted and functions in accordance with the NHMRC National Statement on Ethical Conduct in Human Research.

Appendix F-1: Published article for Chapter 3 in journal published format

Journal of Science and Medicine in Sport 25 (2022) 1002–1007

Contents lists available at ScienceDirect

Journal of Science and Medicine in Sport

journal homepage: www.elsevier.com/locate/jsams

Original research

Validity of low-cost measures for global surveillance of physical activity in pre-school children: The SUNRISE validation study

Tawonga W. Mwase-Vuma [a,b,*], Xanne Janssen [a], Anthony D. Okely [c], Mark S. Tremblay [d,e,f], Catherine E. Draper [g], Alex Antonio Florindo [h], Chiaki Tanaka [i], Denise Koh [j], Guan Hongyan [k], Hong K. Tang [l], Kar Hau Chong [c], Marie Löf [m], Mohammad Sorowar Hossain [n], Penny Cross [c], P.W. Prasad Chathurangana [o], John J. Reilly [a]

[a] School of Psychological Sciences and Health, University of Strathclyde, UK
[b] Centre for Social Research, University of Malawi, Malawi
[c] Early Start, Faculty of the Arts, Social Sciences and Humanities, University of Wollongong, Australia
[d] CHEO Research Institute, Canada
[e] Department of Pediatrics, University of Ottawa, Canada
[f] Department of Health Sciences, Carleton University, Canada
[g] SAMRC/Wits Developmental Pathways for Health Research Unit, University of the Witwatersrand, South Africa
[h] School of Arts, Sciences, and Humanities, University of Sao Paulo, Brazil
[i] Department of Human Nutrition, Tokyo Kasei Gakuin University, Japan
[j] Centre of Community Education & Wellbeing, Faculty of Education, Universiti Kebangsaan Malaysia, Malaysia
[k] Department of Early Childhood Development, Capital Institute of Pediatrics, China
[l] Department of Epidemiology, Faculty of Public Health, Pham Ngoc Thach University of Medicine, Viet Nam
[m] Department of Biosciences and Nutrition, Karolinska Institutet, Sweden
[n] Department of Emerging and Neglected Diseases, Biomedical Research Foundation, Bangladesh
[o] Department of Paediatrics, Faculty of Medicine, University of Colombo, Sri Lanka

A R T I C L E I N F O

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Keywords:
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Parent reports
Pedometer
Child

A B S T R A C T

Objectives: To validate parent-reported child habitual total physical activity against accelerometry and three existing step-count thresholds for classifying 3 h/day of total physical activity in pre-schoolers from 13 culturally and geographically diverse countries.
Design: Cross-sectional validation study.
Methods: We used data involving 3- and 4-year-olds from 13 middle- and high-income countries who participated in the SUNRISE study. We used Spearman's rank-order correlation, Bland–Altman plots, and Kappa statistics to validate parent-reported child habitual total physical activity against *activ*PAL™-measured total physical activity over 3 days. Additionally, we used Receiver Operating Characteristic Area Under the Curve analysis to validate existing step-count thresholds (Gabel, Vale, and De Craemer) using step-counts derived from *activ*PAL™.
Results: Of the 352 pre-schoolers, 49.1 % were girls. There was a very weak but significant positive correlation and slight agreement between parent-reported total physical activity and accelerometer-measured total physical activity (r: 0.140; $p = 0.009$; Kappa: 0.030). Parents overestimated their child's total physical activity compared to accelerometry (mean bias: 69 min/day; standard deviation: 126; 95 % limits of agreement: −179, 316). Of the three step-count thresholds tested, the De Craemer threshold of 11,500 steps/day provided excellent classification of meeting the total physical activity guideline as measured by accelerometry (area under the ROC curve: 0.945; 95 % confidence interval: 0.928, 0.961; sensitivity: 100.0 %; specificity: 88.9 %).

Abbreviations: AUC, area under the ROC curve; CI, confidence interval; ECEC, Early Childhood Education and Care; ECHO, Ending Childhood Obesity; HIC, high-income country; LIC, low-income country; LMVPA, light-moderate-vigorous physical activity; LPA, light physical activity; MIC, middle-income country; MPA, moderate physical activity; MVPA, moderate-to-vigorous physical activity; REDCap, Research Electronic Data Capture; ROC, receiver operating characteristic curve; SD, standard deviation; TPA, total physical activity; UOW, University of Wollongong; USD, United States dollar; WHO, World Health Organization; OECD, Organisation for Economic Co-operation and Development; DAC, Development Assistant Committee.

* Corresponding author.
E-mail address: tawonga.mwase-vuma@strath.ac.uk (T.W. Mwase-Vuma)
@Taomwase.

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Conclusions: Parent reports may have limited validity for assessing pre-schoolers' level of total physical activity. Step-counting is a promising alternative – low-cost global surveillance initiatives could potentially use pedometers for assessing compliance with the physical activity guideline in early childhood.

Practical implications

- Parent reports of their child's level of physical activity are not accurate.
- An alternative simple objective monitoring method is required, especially for low- and-middle-income countries.
- Step-counting (e.g., using pedometers) provides an accurate low-cost option and may be suitable internationally for population monitoring of physical activity in early childhood to improve children's health and prevent obesity and related diseases, such as diabetes, high blood pressure and some cancers.

1. Introduction

In 2016, the World Health Organization (WHO) recommended promotion of physical activity in early childhood as a critical component of the global obesity prevention agenda.[1] Consequently in 2019, the WHO developed the first global guidelines for physical activity, sedentary behaviours and sleep for under 5 s to tackle the obesity pandemic and improve children's health and development.[2] Among pre-schoolers (3–4 years), the WHO recommends daily total physical activity (TPA) of at least 180 min including 60 min of moderate- to vigorous-intensity physical activity (MVPA). Despite the publication of these guidelines in 2019,[2] there is currently no systematic global surveillance of physical activity at this age group across the globe[3] partly due to practical issues like budget limitations and uncertainty over the validity and cultural appropriateness of physical activity surveillance measurements globally. As such, there is a need for a relatively simple, low-cost and sustainable method of surveillance which has criterion validity (against accelerometry) to assess compliance with the guidelines and allow comparisons across studies, cultures, populations, and countries. One obvious option on cost grounds is proxy reports from parents,[4–6] but there is no geographically and culturally validated questionnaire for global surveillance of physical activity in the early years (under 5 s) to date.[3]

So far, only four studies[6–9] have validated parent-reported physical activity against the commonly used criterion measure of accelerometry in children under 5 years: Bacardi-Gascón et al.[8] used light physical activity (LPA), moderate physical activity (MPA), and MVPA; Bingham et al.[9] used MVPA; and the remaining two studies evaluated parent-reported TPA against accelerometer-measured TPA (LPA + MVPA) among 3–5 years old Australian[7] and 4–70 month old Canadian[6] children. However, all of these validation studies[6–9] are limited to a single geographical location and in high income countries (HICs). To the best of our knowledge, there have been no attempts to validate parent-reported TPA against *activ*PAL™ measured TPA (the criterion method) in 3- to 4-year-olds across various countries. *activ*PAL™ is one of the most commonly used research-grade accelerometers for objective measurement of physical activity, and has been validated for measurement of TPA against direct observation in this age group.[10]

Another simple low-cost global alternative to parent reports for global public health surveillance of TPA is step-counting. Over the last decade several studies have developed step-counting thresholds to classify 3 h of TPA in pre-schoolers.[11–13] However, previous studies proposed widely varying step-count thresholds derived from the ActiGraph accelerometers which were equivalent to 3 hour daily TPA[11–13]: Gabel et al.[11] recommended a step-count threshold of 6000 steps/day; Vale et al.[12] suggested 9000 steps/day; and De Craemer et al.[13] suggested 11,500 steps/day. To date, it remains unclear which of these step-count thresholds provides the most accurate measure which might be suitable to use for global surveillance of TPA in pre-school-aged children and whether these thresholds are valid when using different step-count devices and placements.

Therefore, in order to help develop relatively simple methods of physical activity assessment suitable for global public health surveillance in pre-schoolers in future, the aims of our study were to (a) validate parent-reported habitual TPA against *activ*PAL™ measured habitual TPA (calculated as total time spent stepping min/day) in pre-schoolers from geographically and culturally diverse countries, and (b) cross-validate existing step-count thresholds for determining habitual TPA against *activ*PAL™ measured TPA. Given the diversity of our sample, we also explored differences in validation outcomes between parent-reported TPA and accelerometer-measured TPA across the socio-demographic characteristics of study participants.

2. Methods

This study was a secondary analysis of *activ*PAL™ (PAL Technologies Ltd, Glasgow, UK) data collected as part of the first and second pilot phases of the SUNRISE study (https://sunrise-study.com/), an international cross-sectional study of movement behaviours in the early years.[4] The SUNRISE study is being conducted in 43 high-, middle- and low-income countries. Over 2500 children aged 2–6 years from 23 countries have completed the pilot phase of the study, with *activ*PAL™ data available for 955 children from 17 countries. Data are de-identified and available on request from the SUNRISE Coordinating Centre based at the University of Wollongong (UOW), Australia. The SUNRISE study protocol was reviewed and approved by Human Research Ethics Committee at the UOW (2018/044) and ethics committees in each participating country; all parents of participating children gave informed consent.

A total of 352 pre-schoolers aged 3–4 years from 13 countries who participated in the pilot phases 1 and 2 of the SUNRISE study comprised the sample for our validation study. Participants were included in the current study if: (i) they had both *activ*PAL™ and parent-reported habitual TPA data; (ii) they had three valid days of *activ*PAL™ measurement (i.e., a valid day was defined as having 24-h of data), which is appropriate to measure usual level of TPA[14]; and (iii) they were aged 3.0 to <5.0 years. One participant was excluded because the parent-reported level of child physical activity was recorded as zero.

No significant differences in participant characteristics were found between those included and excluded in our study, except for a higher percentage of urban children that have been included in this validation study (59 % vs 44 %). Since future global surveillance of physical activity in children will need to take place in diverse settings, a range of countries (Australia, Bangladesh, Brazil, China, Hong Kong, Indonesia, Japan, Malaysia, South Africa, South Korea, Sri Lanka, Sweden, and Vietnam) and income levels (lower-middle, upper-middle, and high-income countries) were represented in our study.

Habitual TPA by accelerometry was assessed using *activ*PAL™, an activity monitor worn on the thigh with an accelerometer to record time spent sitting/lying, moving/stepping and standing in 15-second epochs.[15] TPA was calculated as the total time spent stepping per day (min/day). *activ*PAL™ has been validated against direct observation of physical activity for measurement of TPA in 3–4 year-olds, with high sensitivity and specificity for measurement of TPA relative to direct observation and no significant bias in measurement of TPA.[10] Children were asked to continuously wear the device on the right anterior thigh, midway between the hip and the knee in the midline, for 3–5 days.[4] This allowed collection of three full days of data (3 × 24-hour period) on TPA. Based on the 2019 WHO Global Guidelines for TPA in children aged 3–4 years,[2] participants were classified as meeting the guideline if they spent an average of at least 180 min/day in TPA.

Habitual TPA by parent reports was assessed using a parent questionnaire completed by self-administration, or interviewer-administered when necessary, for example, where literacy posed challenges.[4] Questions were developed based on available physical activity, sedentary behaviour, and sleep guidelines for the early years.[16] Parents were asked: "On a 24-hour period in the past week, how much time did the 3- to 4-year-old child who is participating in this study spend in a variety of physical activities, spread throughout the day? For example: active play, running, playing with balls, moving to music/dancing, swimming, riding a scooter/tricycle/bike." Parent reports were recorded in hours and minutes and were converted to min/day to calculate parent-reported habitual TPA. This was used to classify participants as meeting the physical activity guideline if they spent an average of at least 180 min/day in TPA.

The habitual number of steps taken was assessed using *activ*PAL™ accelerometers. As noted earlier, *activ*PAL™ records time spent sitting/lying, moving/stepping and standing in 15-second epochs,[15] and it has been validated for measurement of step-counting in older children aged 9–10 years.[17] Since children were asked to wear the device continuously for 3–5 days, its stepping function allowed collection of three full days of data (3 × 24-hour period) on total step-counts. These were used to classify participants as either meeting or not meeting the 180 min/day of TPA in three ways based on the three step-count thresholds in the literature[11–13]: ≥6000 steps/day[11]; ≥9000 steps/day[12]; and ≥11,500 steps/day.[13]

The socio-demographic information of participating children was recorded based on a modified version of the WHO STEPS Survey.[18] Parents reported their child's date of birth (or age in complete years if date of birth was unknown) and this was used to determine the child's age in years and months. Parents reported their child's sex as either boy or girl. The highest level of education completed by the parent or other members of the household was recorded based on each participating country's educational classification and this was then grouped into two categories due to varying educational classifications between countries: low (secondary/high school or below) or high (tertiary education or above) education. Country income level was classified based on the World Bank classification (https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups): lower-middle, upper-middle, and high-income country. However, we treated the two categories for middle-income country (MIC) as one category (i.e., MIC) in our analyses due to fewer children (n = 47) from lower-middle income countries. A child's residential area was recorded as either urban or rural based on the location of the Early Childhood Education and Care (ECEC) centre or community where children were recruited to participate in the SUNRISE study.[4]

Descriptive analyses were performed to describe characteristics of participants and presented as means, standard deviations (SDs), frequency, and percentage (%). We assessed the validity of the parent-reported level of child TPA in meeting the WHO TPA guideline for pre-schoolers in four ways. First, we used Spearman's rank-order correlation (r) to determine the ability of the questionnaire to correctly rank order children by time spent in TPA (min/day) measured by *activ*PAL™. The strength of the correlations was classed as: 0.00–0.19 'very weak'; 0.20–0.39 'weak'; 0.40–0.59 'moderate', 0.60–0.79 'strong'; and 0.80–1.0 'very strong'.[19] Our sample was powered to detect a correlation of r: 0.1489 at 80 % power and 0.05 significance level. Secondly, we used Kappa statistics to assess the ability of parent reports to place individuals in tertiles of habitual TPA measured by accelerometry: strength of agreement was classified using Landis and Koch: <0.00 'poor agreement'; 0.00–0.20 'slight agreement'; 0.21–0.40 'fair agreement'; 0.41–0.60 'moderate agreement'; 0.61–0.80 'substantial agreement'; and 0.81–1.00 'almost perfect agreement'.[20] We also assessed the ability of the questionnaire results to classify participants as meeting (sensitivity) or not meeting (specificity) the TPA guideline by reporting percentage agreement. Sub-group analyses were conducted by the various socio-demographic characteristics (i.e., sex, education class, residential area, and country income level) to explore differences in correlation and classification accuracy between parent-reported TPA and accelerometer-measured TPA. Finally, we used Bland–Altman plots to evaluate bias between parent-reported habitual TPA measure and accelerometry by plotting the difference between the two methods against accelerometry (the criterion method).[21] We also used Bland–Altman plots to calculate 'limits of agreement' (LOA, i.e., mean bias ± 1.96 SD). Additionally, we used Pearson's correlation to test for systematic bias between the difference and the criterion method.

We validated the three proposed step-count thresholds by calculating sensitivity, specificity, and area under the receiver operating characteristic curve (ROC-AUC) for Gabel, Vale & De Craemer step-count thresholds using steps derived from *activ*PAL™.[11–13] The ROC-AUC provides a measure of classification accuracy by graphically plotting the y-axis as true positive rate (sensitivity) and x-axis as false positive rate (1 − specificity). ROC-AUC values were defined as excellent (0.9–1.0), good (0.8–0.9), fair (0.7–0.8), or poor (<0.7).[22] Statistical significance was determined at 5 %. All analyses were performed in Stata/IC v.16.1 for Mac (StataCorp, College Station, Texas, USA) except for ROC-AUC which was performed using SPSS v.27 for Mac (IBM Corp, Armonk, NY, USA).

3. Results

We included 352 pre-schoolers aged 3.0–4.9 years from 13 countries: 3 lower-middle, 5 upper-middle, and 5 high-income countries (Supplementary Table A online). Descriptive characteristics of participants are presented in Table 1. The proportions of boys and girls included in the current study were similar. A slight majority (59.1 %) lived in urban areas and over two-thirds (67.0 %) were from lower- and upper-MICs. The mean age was 4.4 (SD: 0.3) years. Children accumulated an average of 119 (SD: 32) min/day of TPA and accumulated an average of 8784 steps (SD: 2548) as measured by *activ*PAL™. Using the parent reports, children achieved an average of 188 (SD: 127) min/day of TPA.

Table 2 shows rank-order correlations between parent-reported TPA and accelerometer-measured TPA across various socio-demographic characteristics of participants. There was a very weak but statistically significant positive correlation between parent-reported TPA and accelerometer-measured TPA (r: 0.140; p = 0.009). When stratified by various socio-demographic characteristics, correlations ranged from very weak to weak (r: 0.034–0.233). Correlations were statistically significant for boys, participants from highly educated families, and those from MICs.

Overall, there was slight agreement between accelerometer-measured TPA and parent-reported TPA (κ: 0.030) (Table 2). With the various socio-demographic characteristics considered, there remained slight agreement between accelerometer-measured TPA and parent-reported TPA, except among girls where there was disagreement between the two methods (κ: −0.012). Parent reports showed an overall sensitivity of 75.0 % and specificity of 55.2 % for meeting 180 min of TPA guideline per day. When stratified by the various socio-demographic groups, parent reports showed sensitivity of 0.0 %–100.0 % and specificity of 49.6 %–67.3 % for meeting the TPA guideline.

The Bland–Altman plots (Fig. 1) demonstrated an over-estimation of habitual child TPA time from parent reports compared to the *activ*PAL™ measurement (mean bias: 69 min/day; SD: 126; 95 % limits of agreement [LOA]: −179, 316). As shown in Fig. 1, most parents with less active children over-reported their child's habitual TPA. There was also

Table 1
Descriptive characteristics of study participants (as frequency and percentage unless specified).

	Frequency	Percent
Sex		
Boys	179	50.9
Girls	173	49.1
Education class		
High	183	52.0
Low	165	46.9
Missing	*4*	*1.1*
Residential area		
Urban	208	59.1
Rural	144	40.9
Country income level[a]		
HICs	116	33.0
MICs	236	67.0

	Frequency	Mean (SD)
Age, years	352	4.4 (0.3)
Accelerometer total physical activity, min/day	352	118.9 (31.7)
Parent-reported total physical activity, min/day	352	187.6 (126.9)
Total step-count, steps/day	352	8783.6 (2548.2)

Note: HIC = high-income countries; MICs = middle-income countries.
[a] Derived variable based on World Bank classification.

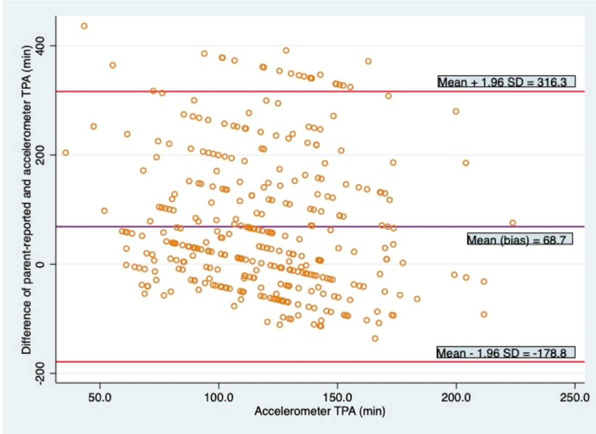

Fig. 1. A 'modified' Bland–Altman plot between accelerometer-measured child habitual TPA and parent-reported child habitual TPA. The figure shows mean bias (middle solid line) of 69 min/day in (over-)estimation of a child's TPA by parent reports compared to accelerometer measurement and its associated lower and upper limits of agreement (below and above the mean bias line, respectively). The dots indicate that over-reporting of a child's TPA by parent reports was higher among less active children.

systematic bias in the measurement of child TPA by parent reports compared to accelerometer data, as parents tended to over-report their child's habitual TPA to a larger extent in less active children (r: −0.106; $p = 0.047$).

The ROC analyses showed excellent classification accuracy for the De Craemer et al.[13] step-count cut-point with an AUC of 0.945 (95 % CI: 0.928, 0.961), 100.0 % sensitivity and 88.9 % specificity (Supplementary Fig. A online). The Vale et al.[12] cut-point showed a fair classification accuracy (AUC: 0.773; 95 % CI: 0.747, 0.799, sensitivity: 100.0 %; specificity: 54.6 %), and the Gabel et al.[11] step-count cut-point showed a poor classification accuracy (AUC: 0.577; 95 % CI: 0.557, 0.595; sensitivity: 100.0 %; specificity: 15.1 %).

4. Discussion

Our findings suggest that simple parent-reporting of child TPA is not likely to be adequate for global surveillance of the WHO physical activity guideline for pre-schoolers. However, we found that step-counting, using the De Craemer et al.[13] step-count threshold of 11,500 steps/day, provided an accurate way of assessing compliance with the guideline in this diverse group of pre-schoolers.

Only two studies have evaluated parent-reported TPA against accelerometry in young children.[6,7] Dwyer et al.[7] found very weak correlations ranging between 0.05 and 0.16 which were not statistically significant ($p > 0.05$). Additionally, Dwyer et al.[7] reported mean biases of parent-reported TPA against accelerometry of 45 min/day (LOA: −104, 194) and 21 min/day (LOA: 122, 164) based on Sirard et al.[23] and Reilly et al.[24] accelerometry cut-points, respectively. Unlike our study, findings from Dwyer et al[7] were limited by a small sample size ($n = 67$). Sarker et al.[6] found a weak correlation of 0.39 (95 % CI: 0.19, 0.56) between parent-reported child habitual TPA and accelerometer-measured child habitual TPA, which is higher than the correlation in our study (r: 0.14; $p = 0.009$). Unlike Sarker et al.[6] which used Actical accelerometers, our study used *activ*PAL™ accelerometers which have been validated for measurement of TPA against direct observation in

Table 2
Spearman's correlation and classification accuracy between parent-reported and accelerometer-measured levels of TPA.

	Spearman's correlation		Classification accuracy			
	Coefficient (r)	p-Value	Agreement (%)	Sensitivity (%)	Specificity (%)	Kappa (κ)
All	0.140	0.009	56.0	75.0	55.5	0.030
Sex						
Boys	0.171	0.022	53.6	85.7	52.3	0.058
Girls	0.088	0.249	58.4	0.0	58.7	−0.012
Education class[a]						
High	0.233	0.002	57.9	66.7	57.6	0.035
Low	0.034	0.665	54.6	100.0	54.0	0.028
Residential area						
Urban	0.108	0.120	59.6	60.0	59.6	0.022
Rural	0.157	0.060	50.7	100.0	49.6	0.039
Country income level[b]						
HIC	0.112	0.233	67.2	66.7	67.3	0.050
MIC	0.156	0.016	50.4	80.0	49.8	0.024

Note: HIC = high-income countries; MICs = middle-income countries.
Agreement means the proportion of children who were accurately classified by both the parent reports and accelerometry (the criterion method) as meeting or not meeting the TPA guidelines.
Sensitivity means proportion of children who are accurately classified as meeting the TPA guidelines by parent reports.
Sensitivity means proportion of children who are accurately classified as not meeting the TPA guidelines by parent reports.
Kappa statistics by Landis and Koch[20]: <0.00 'poor agreement'; 0.00–0.20 'slight agreement'; 0.21–0.40 'fair agreement'; 0.41–0.60 'moderate agreement'; 0.61–0.80 'substantial agreement'; and 0.81–1.00 'almost perfect agreement'.
[a] 4 participants with missing data.
[b] Derived variable based on World Bank classification.

this age group.[10] Sarker et al.[6] had a mixed sample, involving infants, toddlers, pre-school and schoolchildren aged 4–70 months and did not report correlation/agreement specifically for each age group. The present study only included pre-schoolers aged 3–4 years that may have different activity patterns as well as spend less time with their parents compared to younger children in the Sarker et al.[6] study. Additionally, participants in both previous studies were from HICs[6,7]; whereas our study included participants from lower- and upper-middle-income countries and with diverse culture and lifestyles. Nevertheless, the results of the current study are consistent with a previous review of validation studies of physical activity measures in children, even though most validation studies included in the review involved children older than those participating in our study.[25] The poor/weak correlation in validation studies of parent-reported physical activity could be caused by parents over-reporting their child's physical activity due to social desirability[26] or because they do not know how much activity their child participates in during weekdays when they are at an ECEC centre for example.

Despite the importance of TPA in early childhood for current child health and development, and future health according to the WHO Ending Childhood Obesity (ECHO) Report[1] and WHO 2019 Guidelines,[2] there is currently no systematic global surveillance.[3] There is global surveillance of adherence to WHO physical activity guidelines in adolescents[27] and adults.[28] Whilst proxy reports from parents are simple and cheap for monitoring physical activity in young children, our results suggest that they are not likely to be valid for global public health surveillance of physical activity in early childhood. Consequently, parent questionnaires may not be suitable for monitoring compliance with the WHO physical activity guidelines in early years. Given the need for a globally validated physical activity measurement for surveillance purposes to monitor progress towards the global targets, and based on our results, step-counting may be a more accurate alternative to parent reports. At the moment, there is currently no consensus on culturally and geographically valid step-count targets for classifying 3 h of TPA in pre-schoolers.[11–13] The present study suggests that a step-count threshold of at least 11,500 steps/day[13] be used for assessing compliance with meeting the TPA guideline in early years because it is geographically and culturally valid against TPA measured by *activ*PAL™. There are barriers to using accelerometers in population-based studies as they are intrusive, require complicated data reduction and analysis, produce huge data sets, and are expensive,[5,9] at about a minimum of $254 USD per device up to >$1000 USD, depending on the device. As such, surveillance studies and national surveys in future could potentially use much simpler, cheaper devices like pedometers to assess the prevalence of compliance with WHO guidelines. Pedometers are highly correlated to accelerometer step-counts in young children[17,29] and adults[30]; however, exact step-count thresholds should be established as being accurate in the population that they are being used before being included as surveillance measures due to potential differences between methods of measuring step-counts (including differences due to the placement of the device, e.g. with *activ*PAL™ worn on the thigh and pedometers usually worn on the hip).

A strength of our study was the relatively large sample of young children compared to previous validation studies among this age group.[6–9] Moreover, to our knowledge, this is the first study to assess validity of parent reports of their children's physical activity based on a sample from vastly differing contexts, including lower- and upper-MICs as well as HICs. This is also the first study to cross-validate existing step-count thresholds in such a varied sample of pre-schoolers.

Our study had some limitations. Recruitment of participants in the SUNRISE study was determined independently in each country due to the varying contexts in which the study was conducted, including use of convenience cluster sampling.[4] The sample was not representative. However for a methodological study the main requirements are adequate sample size, wide range of settings, and a range of levels of TPA from low to high, and all these requirements were met in our study. We did not have any low-income country (LIC) study participants as classified by the World Bank. However, our study included participants from Bangladesh which is classified as a LIC according to the Organisation for Economic Co-operation and Development's (OECD) Development Assistant Committee (DAC; https://www.oecd.org/dac/financing-sustainable-development/development-finance-standards/daclist.htm) and also included three lower-MICs. The parent-reported questions in our study were based on available physical activity, sedentary behaviour, and sleep guidelines for the early years,[16] and alternative questions might have higher validity. In addition, it is possible that the observed bias in over-reporting of a child's TPA by parents varied between countries due to cultural differences; however, with our sample size we were not adequately powered to explore differences in biases by country of origin. As such, a further study focusing on potential differences in the biases in physical activity reporting by parents across countries may be useful. We identified a gender difference in accuracy of parent reporting of TPA (more accurate in the boys than girls) – the reasons for this are not clear and may be worth investigating further in future. However, correlations between parent-reported TPA and accelerometer-measured TPA, though statistically significant, were very low in the boys in the present study and so the practical significance of this gender difference is probably quite limited – validity of parent reporting was low in both boys and girls. Further, we used a research-grade accelerometer to test the three existing step-count thresholds and therefore cheaper pedometers need to be validated before use. Lastly, there was a suggestion of a possible gender difference in the classification accuracy as there was disagreement between the two methods in measurement of habitual TPA among girls which also requires further research.

5. Conclusions

Despite the importance of TPA in early childhood for current child health and development, and future health according to the WHO ECHO Report[1] and WHO 2019 Guidelines,[2] there is currently no global surveillance of TPA in early childhood, and one major barrier to a surveillance system is cost and complexity of the measurement method. The present study provides evidence that parent reports may have limited validity for this purpose as parents cannot recall their child's physical activity adequately, at least not using fairly simple questions. However, our study also shows that step-counts may be an accurate and relatively simple, potentially low-cost, alternative to assessment of progress towards meeting the global physical activity targets in this age group.

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CRediT authorship contribution statement

TM-V, XJ, and JJR contributed to the conceptualisation, data analysis and interpretation, drafting, review, and final approval of the manuscript. ADO, MST, CED, AAF, CT, DK, GH, HKT, KHC, ML, MSH, PC, and PWPC contributed to data acquisition as well as reviewed and approved the manuscript.

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Confirmation of ethical compliance

The SUNRISE study protocol was reviewed and approved by Human Research Ethics Committee at the UOW (2018/044) and ethics committees in each participating country; all parents of participating children gave informed consent.

Declaration of interest statement

None.

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References

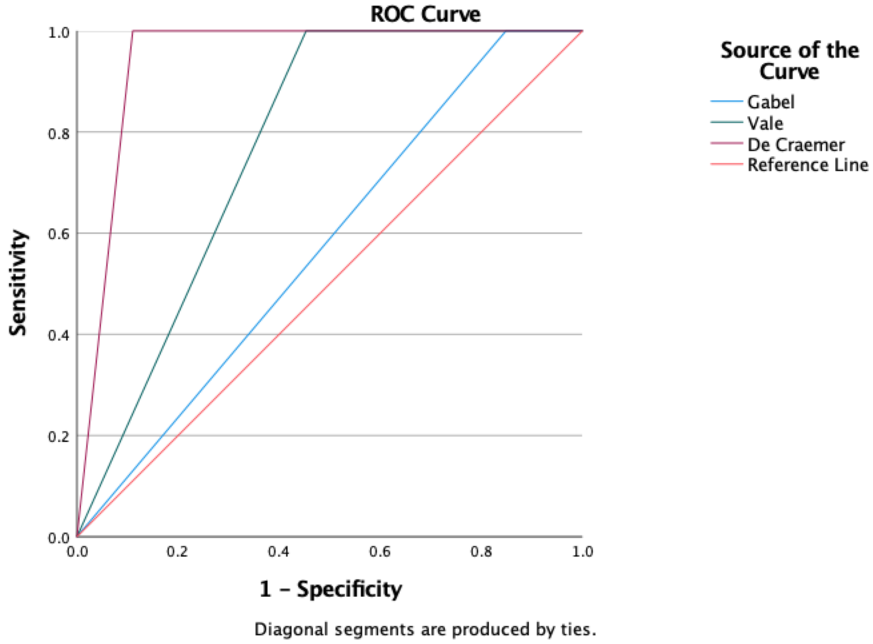
1. World Health Organization. *Report of the Commission on Ending Childhood Obesity*, 2016.
2. World Health Organization. *World Health Organisation Guidelines for Physical Activity, Sedentary Behaviour, and Sleep for Children Under 5 Years of Age*, 2019.
3. Aubert S, Brazo-Sayavera J, González SA et al. Global prevalence of physical activity for children and adolescents; inconsistencies, research gaps, and recommendations: a narrative review. *Int J Behav Nutr Phys Act* 2021;18(1):1-11. doi:10.1186/s12966-021-01155-2.
4. Okely AD, Reilly JJ, Tremblay MS et al. Cross-sectional examination of 24-hour movement behaviours among 3- and 4-year-old children in urban and rural settings in low-income, middle-income and high-income countries: the SUNRISE study protocol. *BMJ Open* 2021;11(10):e049267. doi:10.1136/bmjopen-2021-049267.
5. Hidding LM, Chinapaw MJM, Van PMNM et al. An updated systematic review of childhood physical activity questionnaires. *Sports Med* 2018;48(12):2797-2842. doi:10.1007/s40279-018-0987-0.
6. Sarker H, Anderson LN, Borkhoff CM et al. Validation of parent-reported physical activity and sedentary time by accelerometry in young children. *BMC Res Notes* 2015;8:735. doi:10.1186/s13104-015-1648-0.
7. Dwyer GM, Hardy LL, Peat JK et al. The validity and reliability of a home environment preschool-age physical activity questionnaire (Pre-PAQ). *Int J Behav Nutr Phys Act* 2011;8(86):1-13. doi:10.1186/1479-5868-8-86.
8. Bacardi-Gascón M, Reveles-Rojas C, Woodward-lopez G et al. Assessing the validity of a physical activity questionnaire developed for parents of preschool children in Mexico. *J Health Popul Nutr* 2012;30(4):439-446. doi:10.3329/jhpn.v30i4.13327.
9. Bingham DD, Collings PJ, Clemes SA et al. Reliability and validity of the Early Years Physical Activity Questionnaire (EY-PAQ). *Sports* 2016;4(2):1-14. doi:10.3390/sports4020030.
10. Davies G, Reilly JJ, Mcgowan AMYJ et al. Validity, practical utility, and reliability of the activPAL in preschool children. *Med Sci Sports Exerc* 2012;44(4):761-768. doi:10.1249/MSS.0b013e31823b1dc7.
11. Gabel L, Proudfoot NA, Obeid J et al. Step count targets corresponding to new physical activity guidelines for the early years. *Med Sci Sports Exerc* 2013;45(2):314-318. doi:10.1249/MSS.0b013e318271765a.
12. Vale S, Trost SG, Duncan MJ et al. Step based physical activity guidelines for preschool-aged children. *Prev Med (Baltim)* 2015;70(January):78-82. doi:10.1016/j.ypmed.2014.11.008.Copyright.
13. De Craemer M, De Decker E, De Bourdeaudhuij I et al. The translation of preschoolers' physical activity guidelines into a daily step count target. *J Sports Sci* 2015;33(10):1051-1057. doi:10.1080/02640414.2014.981850.
14. Cliff DP, Reilly JJ, Okely AD. Methodological considerations in using accelerometers to assess habitual physical activity in children aged 0–5 years. *J Sci Med Sport* 2009;12(5):557-567. doi:10.1016/j.jsams.2008.10.008.
15. De Decker E, De Craemer M, Santos-Lozano A et al. Validity of the ActivPALTM and the ActiGraph monitors in preschoolers. *Med Sci Sports Exerc* 2013;45(10):2002-2011. doi:10.1249/MSS.0b013e318292c575.
16. Okely AD, Ghersi D, Hesketh KD et al. A collaborative approach to adopting/adapting guidelines - the Australian 24-Hour Movement Guidelines for the early years (birth to 5 years): an integration of physical activity, sedentary behavior, and sleep. *BMC Public Health* 2017;17(Suppl 5):896. doi:10.1186/s12889-017-4867-6.
17. Aminian S, Hinckson EA. Examining the validity of the ActivPAL monitor in measuring posture and ambulatory movement in children. *Int J Behav Nutr Phys Act* 2012;9:1-9. doi:10.1186/1479-5868-9-119.
18. World Health Organization. The STEPS Instrument. The STEPS Instruments. https://www.who.int/ncds/surveillance/steps/instrument/en/. Accessed 19 October 2019.
19. Fowler J, Cohen L, Jarvis P. *Practical Statistics for Field Biology, 2nd ed.*, John Wiley & Sons Ltd, 2009.
20. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics* 1977;33(1):159. doi:10.2307/2529310.
21. Krouwer JS. Why Bland–Altman plots should use X, not (Y + X)/2 when X is a reference method. *Stat Med* 2008;27(5):778-780. doi:10.1002/sim.3086.
22. Mehdi T, Ahmadi BN. Kernel smoothing for ROC curve and estimation for thyroid stimulating hormone. *Int J Public Health Res Spec Issue* 2011:239-242. [Published online].
23. Sirard JR, Trost SG, Pfeiffer KA et al. Calibration and evaluation of an objective measure of physical activity in preschool children. *J Phys Act Health* 2005;2(3):345-357. doi:10.1123/jpah.2.3.345.
24. Reilly JJ, Coyle J, Kelly L et al. An objective method for measurement of sedentary behavior in 3- to 4-year olds. *Obes Res* 2003;11(10):8-11. doi:10.1038/oby.2003.158.
25. Adamo KB, Prince SA, Tricco AC et al. A comparison of indirect versus direct measures for assessing physical activity in the pediatric population: a systematic review. *Int J Pediatr Obes* 2009;4(1):2-27. doi:10.1080/17477160802315010.
26. Shephard RJ. Limits to the measurement of habitual physical activity by questionnaires. *Br J Sports Med* 2003;37:197-206. doi:10.1136/bjsm.37.3.197.
27. Guthold R, Stevens GA, Riley LM et al. Global trends in insufficient physical activity among adolescents: a pooled analysis of 298 population-based surveys with 1·6 million participants. *Lancet Child Adolesc Health* 2020;4(1):23-35. doi:10.1016/S2352-4642(19)30323-2.
28. Bonita R, de Courten M, Dwyer T et al. *Surveillance of Risk Factors for Noncommunicable Diseases: The WHO STEPwise Approach. Summary*, 2001. [Published online].
29. De Craemer M, De Decker E, Santos-Lozano A et al. Validity of the Omron pedometer and the actigraph step count function in preschoolers. *J Sci Med Sport* 2015;18(3):289-293. doi:10.1016/j.jsams.2014.06.001.
30. Behrens TK, Dinger MK. Comparisons of accelerometer and pedometer determined steps in free living samples. *J Phys Act Health* 2011;8(3):390-397. doi:10.1123/jpah.8.3.390.

Appendix F-2: Supplementary material for published article for Chapter 3

Supplementary materials

Supplementary Table A: List of countries where participants for the SUNRISE Study were recruited, by income level.

Country	**Frequency**	**Percent**
High-income countries		
Australia	3	2.6
Hong Kong	69	59.5
Japan	32	27.6
South Korea	10	8.6
Sweden	2	1.7
Total	116	100.0
Upper-middle income countries		
Brazil	37	19.6
China	57	30.2
Malaysia	55	29.1
South Africa	17	9.0
Sri Lanka	23	12.2
Total	189	100.0
Lower-middle income countries		
Bangladesh	21	44.7
Indonesia	20	42.5
Vietnam	6	12.8
Total	47	100.0



Supplementary Figure A: ROC curve for the three existing step-count thresholds. A ROC-AUC value of 0.9-1.0 is considered excellent classification whereas a value <0.7 is considered poor classification. Ideally, a low value on the x-axis (1 – Specificity) and a high value on the y-axis (Sensitivity) means a ROC-AUC value closer to 1.0. Compared to the other two step-count thresholds, the De Craemer et al. threshold of 11,500 steps/day shows excellent classification as it maximised the sensitivity (true positives) and minimised the false positives (1 – Specificity) in classifying children as meeting or not meeting the 2019 WHO guideline of 180 min/day of TPA in pre-schoolers.

Appendix G-1: Published article for Chapter 4 in journal published format

The published version of this article has been redacted for copyright reasons. The AAM version can be found in Chapter 4 of this thesis. The final published version can be found in Journal of Physical Activity and Health, 2024, 21,794-801 https://doi.org/10.1123/jpah.2023-0711

The published version of this article has been redacted for copyright reasons. The AAM version can be found in Chapter 4 of this thesis. The final published version can be found in Journal of Physical Activity and Health, 2024, 21,794-801 https://doi.org/10.1123/jpah.2023-0711

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Appendix G-2: Supplementary material for published article for Chapter 4

Supplementary Table 1: Proportion of participants meeting the WHO TPA guideline based on the 11,500 steps/day threshold on average among pre-school children.

Variables	Frequency	Percent	95% CI
All	246	30.9	27.6, 34.2
Sex			
Boys	139	34.3	29.8, 39.1
Girls	107	27.3	23.1, 31.9
Age group in years			
3.0 to 3.9	62	46.6	38.3, 55.1
4.0 to <5.0	184	27.7	24.4, 31.2
Education class			
High	114	26.8	22.8, 31.2
Low	123	34.9	30.1, 40.1
Residential area			
Urban	109	26.0	22.0, 30.4
Rural	137	36.2	31.5, 41.2
Country income level			
HIC	96	32.0	27.0, 37.5
Upper-MIC	67	21.7	17.4, 26.6
Lower-MIC	83	44.1	37.2, 51.3

Notes: CI, confidence interval; HIC, high-income countries; MIC, middle-income countries; Low education class means secondary/high school or below; High education class means tertiary education or above

Appendix H: Activity monitor log

International Study
of 24-hour movement behaviours in the early years

Activity Monitor Log

Dear Parent/Caregiver,

Please record your child's wake-up time and bedtime to the closest possible minute every day and let us know if the monitor has been taken off during sleep. We would like your child to wear the monitor at all times of the day and night, except when showering/taking a bath or swimming.

Day	Date	Wake-up time	Bed-time	Did your child sleep with the monitor on?			Did you child go to childcare centre today?	
				Yes	No	If No, why?	Yes	No
Eg.	*17/6/22*	*6.30am*	*8.30pm*	/			/	
0*								
1								
2								
3								
4*								
Do you have any comments about wearing the monitor?								

Please return this log together with the monitor on ....

Thank you for your time and your cooperation!

For further information please contact Tawonga Mwase-Vuma on 0999 198 662, or email tmwase-vuma@unima.ac.mw or Janine Kayange 0995 172 847

*Day 0 is the day the accelerometer is put on the child and Day 4 is the day it is removed

Appendix I: Activity monitor instructions sheet

THE SUNRISE STUDY
MOVEMENT BEHAVIOURS IN EARLY CHILDHOOD IN MALAWI

Activity Monitor Instruction Sheet

Dear Parent/Caregiver,

Thank you for taking part in this important study. Here are a few points to remember over the **next 5 days**.

- Please make sure your child wears the monitor every day and night, except when showering/taking a bath or swimming. **REMEMBER TO PUT IT BACK ON AS SOON AS POSSIBLE**

- Please make sure your child wears the monitor on your right hip, in a straight line down from the front of your armpit (see picture).
- Ensure that the black circle on the monitor is facing up
- The monitor can be worn on top or underneath clothes, whichever is most comfortable

- Your child can continue his/her usual activities.

- Let him/her HAVE FUN!

We will collect the monitor of your child on…………………………………………………………..

Thank you for your time and your cooperation!

For further information please contact Tawonga Mwase-Vuma on 0999 198 662, or email tmwase-vuma@unima.ac.mw or Janine Kayange 0995 172 847

Appendix J: SUNRISE ActiGraph accelerometry data checking and analysis protocol

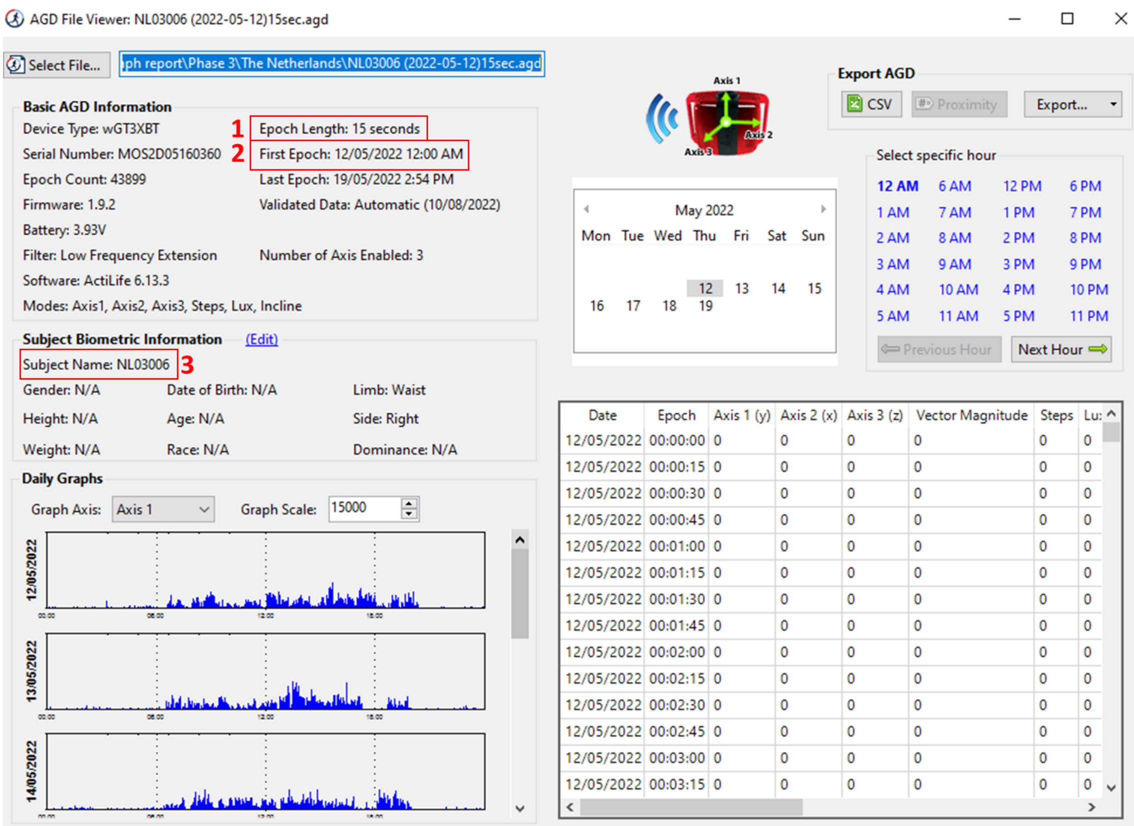
SUNRISE SOP: Accelerometry (Actigraph) Data Checking and Analysis

What is required for the data checking and analysis?

- Exported data file (.agd) in 15-second epoch length (download from Country's Accelerometry folder on CloudStor)
- ActiLife software with the full activation licence
- A data check excel file for each country (refer to *'AG Data Check, template.xlsx'*)
- A log diary csv file for each country (refer to *'AG Log Diary, template.csv'*)
- Child's sleep schedule data from parent/caregiver questionnaire (average bedtime and wake-up time for each country)
- Create a subfolder for each country on the server (*Monitor Analysing -> Actigraph report*) to store all data and output files related to the accelerometry analysis.

Step 1: Check if the accelerometer data has been collected and downloaded from the monitor as per the study protocol

1.1 Double click on the downloaded .agd file and an AGD File Viewer window displaying the data information will appear as below:



1.2 Check and make sure the information appeared in the following sections is correct:

1) Epoch Length: Should be 15 seconds. If not, you can re-export the .agd file into the specified epoch length by using the gt3x raw data file (see Others section).

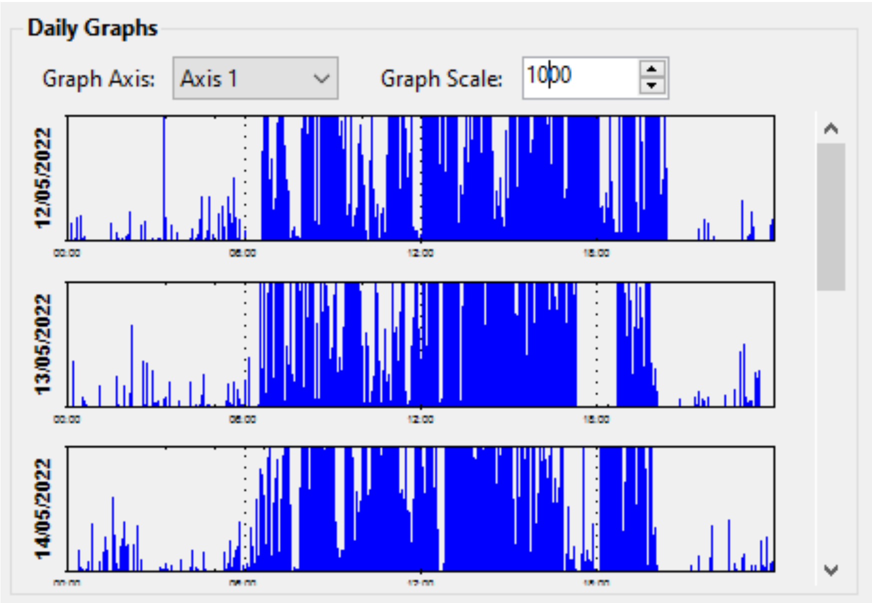
2) First Epoch: The starting time should be set as 12:00AM as the monitor should be initialised to start recording from the midnight of the day on which the monitor is to be

placed on the child. If this is incorrect, please let the Country know and remind them to always set it as 12:00AM.

3) Subject Name: This should be the same as the Child ID appeared in the file name (e.g., NL03006). If not, change it to the correct ID by clicking on the Edit button (next to 'Subject Biometric Information'). Please also let the Country know that they should rename this field using the correct Child ID before downloading the data from the monitor (refer to Protocol Manual for more detailed instructions).

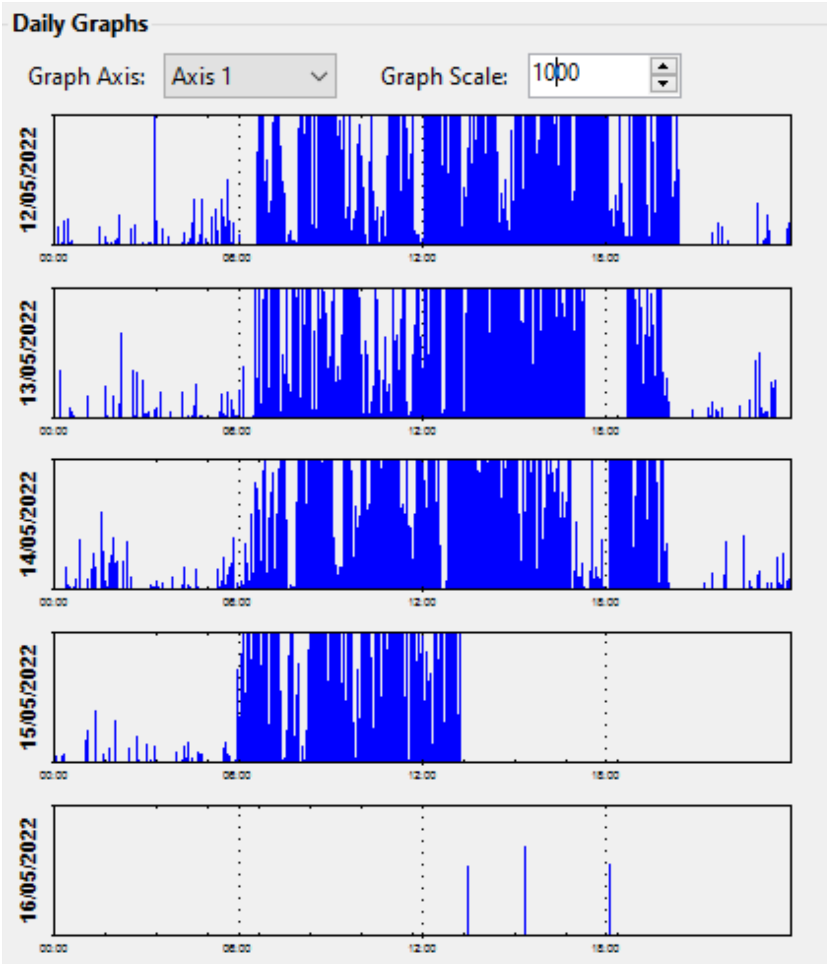
<u>Step 2: Identify day(s) with 'valid' 24-h data</u>

2.1 Scroll down to the Daily Graphs section and change the Graph Scale to a smaller value (e.g, 1000) so that the acceleration/movement peaks across the 24-h period for each recording day (displayed in the midnight-to-midnight format) can be viewed easily.



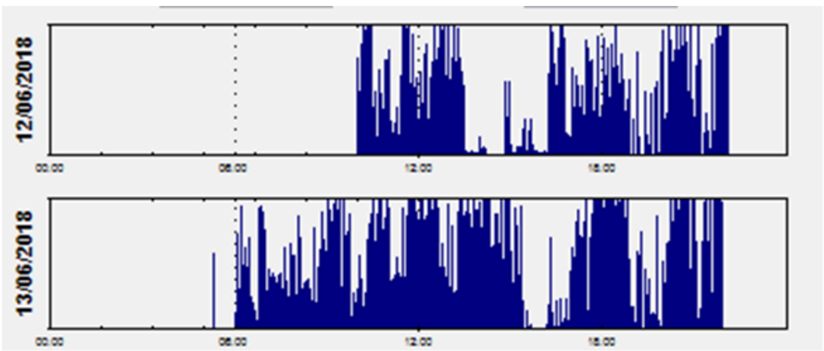
2.2 At the data screening stage, a 'valid' 24-h day is defined based on the distribution patterns of the acceleration/movement peaks (Note: Higher peak mean greater magnitude of movement detected e.g., PA). If there were none during the sleeping period (and during the day) we assume the child took the monitor off and this particular day will then be classified as invalid and excluded from the analysis. However, we did not do any calculation of non-wear time at this stage as it was mainly to identify if the child did wear the monitor continuously over the 24h period especially during sleeping period (i.e. compliance with the 24-h monitoring protocol).

<u>Example 1:</u>



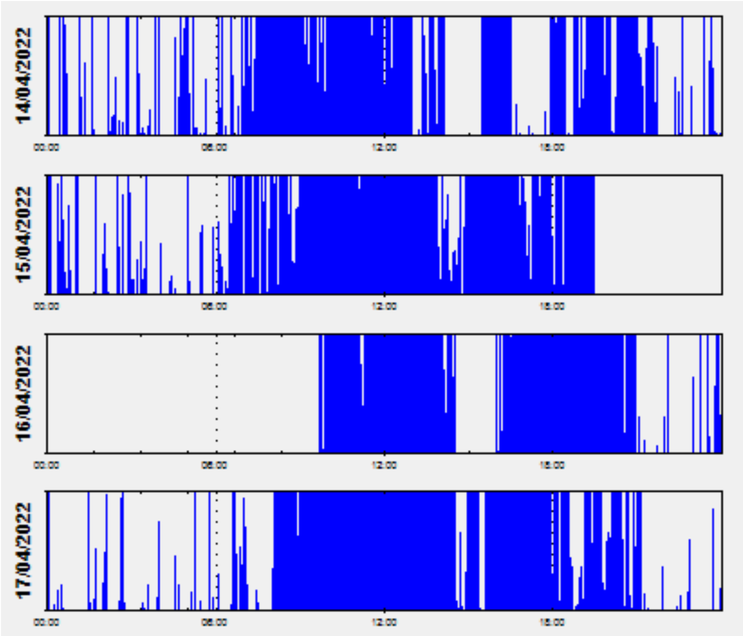
This graph tells us that the child had worn the monitor continuously for both day and night time on 12/05, 13/05 and 14/05. However, on 15/05, the monitor appeared to be taken off after 2PM as there were no/very little movements detected since then. In this case, we conclude that this child has three days of valid 24-h accelerometry data (i.e., 12/05-14/05) for the analysis.

<u>Example 2:</u>



This graph tells us that the child only worn the monitor during daytime but not during night time on 12/06 and 13/06. Hence both days are considered invalid and will be excluded from the analysis.

<u>Example 3:</u>



This graph tells us that the child had worn the monitor from the midnight of 14/04 but took it off during the overnight sleep period of 15/04 -16/04 (from ~8pm until ~10am). In this case, only 14/04 AND 17/04 are be considered as valid 24-h days for the analysis.

<u>Step 3: Create and update data check and log diary documents</u>

Create and update the data check and log diary documents for each country by entering the number of day(s) (for data check file) and date (for log diary) with valid 24-h accelerometry data based on the data screening:

<u>Data check document (refer to *'AG Data Check, template.xlsx'*)</u>

For each child ID with parental consent received on REDCap, insert Y/N under each column indicating whether or not the child had had at least 24-h (1 day), 48-h (2 days) or 72-h (3 days) of accelerometry data for the analysis. Leave a note in the Comments column if the child had more than 3 days of accelerometry data or the reasons for not having valid data (e.g., not worn for sleep, no data recorded, lost monitor, missing data file and etc.). Please add this to the country's finalised dataset (*'SUNRISEPILOT/MAIN_COUNTRYCODE_AG*_DataCheck').

<u>Example:</u>

Child ID	ActiGraph			Comments
	Valid 24H	Valid 48H	Valid 72H	
AU01001	*Y*	*Y*	*Y*	*4 days of data*
AU01002	*N*	*N*	*N*	*Not worn for sleep*
AU01003	*N*	*N*	*N*	*No data recorded*
AU01004				*Lost monitor*
AU01005	*Y*	*Y*	*N*	*No data for evening on the last measuring day*

<u>Log diary (refer to *'AG Log Diary, template.csv'*)</u>

This document should only include children who provided at least one valid 24-h day of accelerometry data as determined from the data screening process (i.e., AU01001 and

4

AU01005 as indicated in the example above). It will then be imported to the ActiLife software to restrict the accelerometry analysis to the specified date(s) per valid data file.
Example:

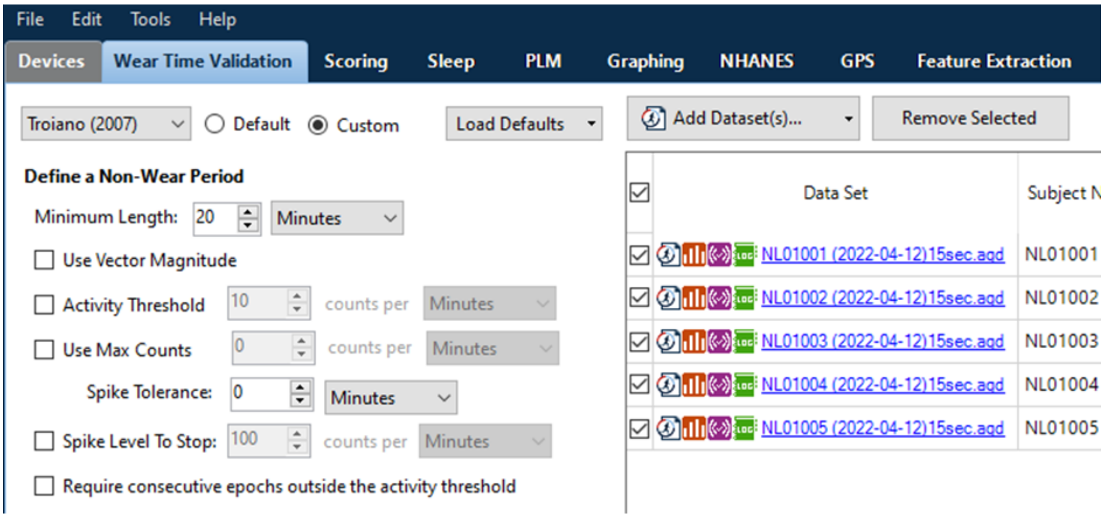
Subject Name	On Date	On Time	Off Date	Off Time
AU01001	12/04/2022	12:00 AM	15/04/2022	11:59:59pm
AU01005	12/04/2022	12:00 AM	13/04/2022	11:59:59pm
AU01006	12/04/2022	12:00 AM	12/04/2022	11:59:59pm
AU01006	14/04/2022	12:00 AM	14/04/2022	11:59:59pm

- On Date: This should be the date of the first valid day.
- Off Date: This should be the date of the last valid day.

Note:
- Keep the On Time and Off Time as 12:00AM and 11:59:59PM, respectively.
- If the child had only one valid day of data, then the Off Date should be the same as Off Date.
- If the child had valid data for the first and third measuring days but not for the second day (i.e., AU01006 in the example above), two rows should be created: the first row includes the date of the first day (for both On Date and Off Date) and the second row includes the date of the third day. This will enable the analysis to specifically include data recorded on the first and third measuring days.

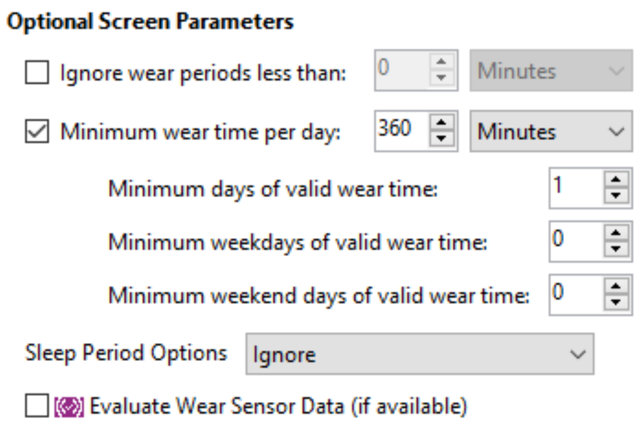
Step 4: Data analysis: Detection of non-wear periods
The *Wear Time Validation* tab on the ActiLife software screen allows users to flag periods of non-wear, essentially filtering out those periods for further analysis.

4.1 Import the valid .agd data files by clicking *Add Dataset(s)*.

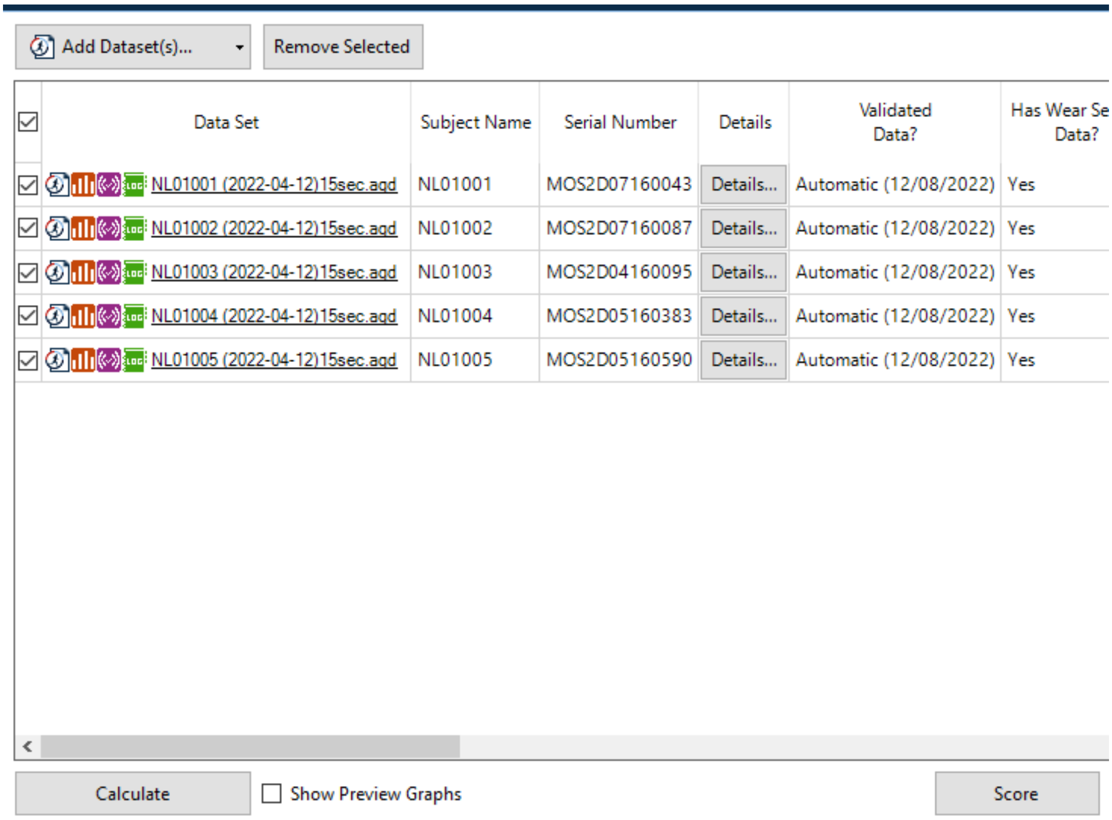


4.2 Under *Define a Non-Wear Period*: Enter **20 minutes** into the Minimum Length column and keep other sections blank/zero (see screenshot above).

4.3 Under *Optional Screen Parameters*: Tick the *Minimum wear time per day* option and enter **360 minutes** for the analysis, then enter **1 day** for the *Minimum days of valid wear time* option.

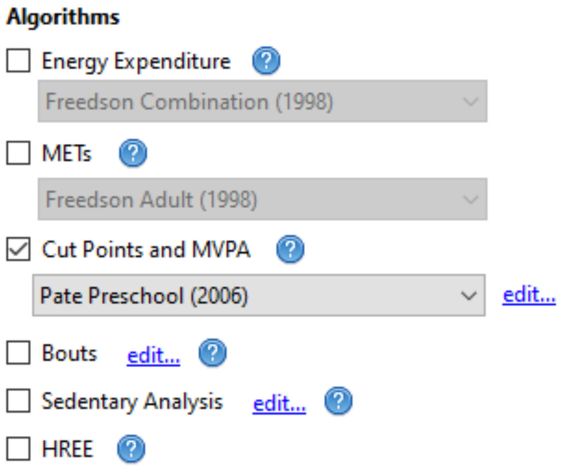


4.4 Click *Calculate* to detect the non-wear time period within the data files. Once this is done, click *Score* to proceed to *Data Scoring* tab for the next stage of analysis.

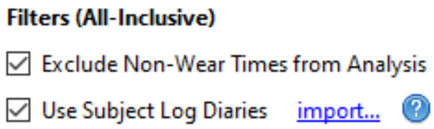


Step 5: Data analysis: Classification of activity intensity

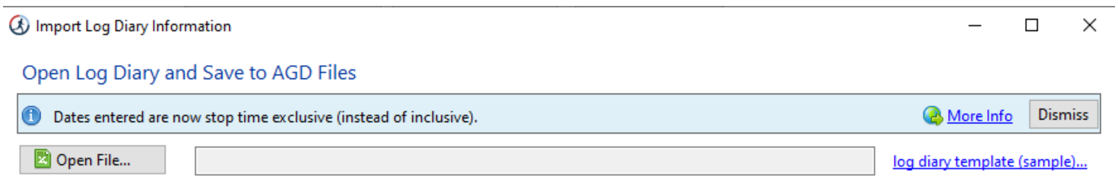
5.1 Under *Algorithms*: Tick *Cut Points and MVPA* and select Pate Preschool (2006) from the dropdown list.



5.2 Under *Filters (All Inclusive)*: Tick both *Exclude Non-Wear Times from Analysis* and *Use Subject Log Diaries* option.

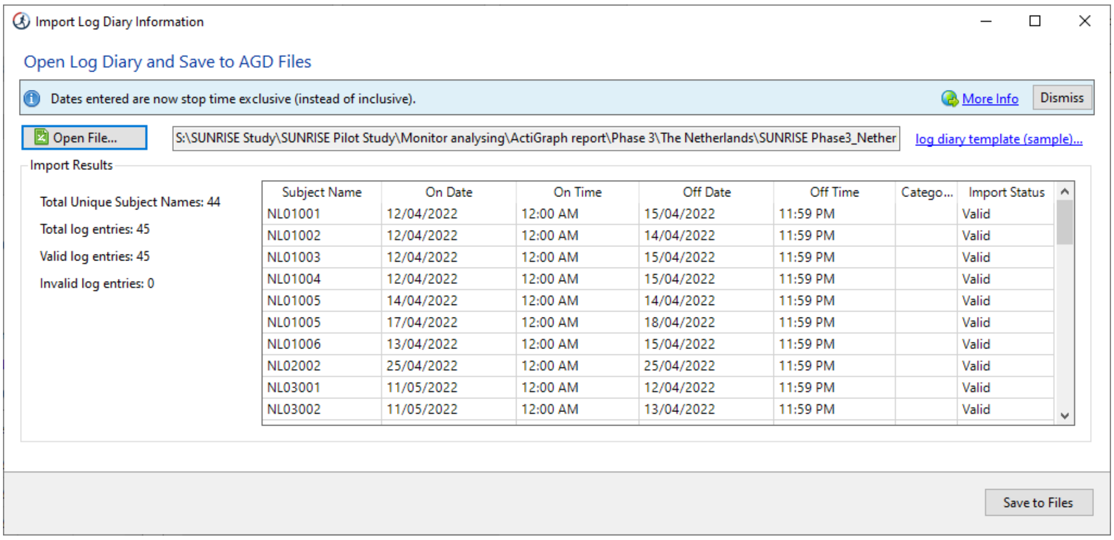


5.3 Click *import…* next to Use Subject Log Diaries. A *Import Log Diary Information* window will then appear. Click *Open File* to locate and import the log diary csv file.

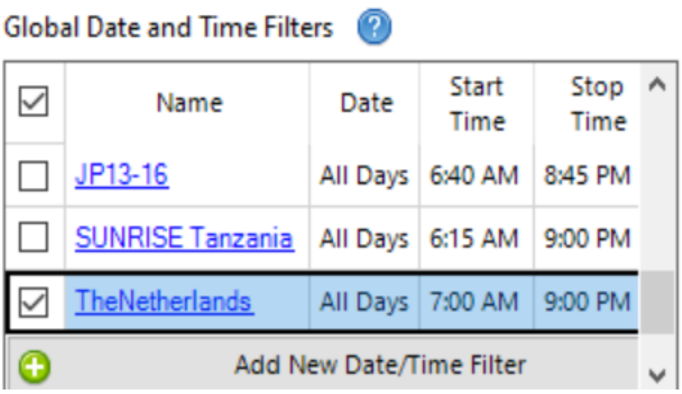


5.4 Once the log diary file is imported, check the *Import Status* column and see if there is a mismatch of ID/date of measurement between the log diary and the .agd data file. Eg. if the Subject Name was entered as AUD01001 in the log diary but 01001 in the .agd data file, it will be detected as an *Invalid log entries* and the log diary data will not be able to use for this child's data file. To correct this error, please make sure the same ID is entered in both .agd data file and log diary.

If the **Invalid log entries** under the *Import Results* section is displayed as zero (i.e., everything is correct), click *Save to Files* to integrate the log diary data into the analysis.



5.5 Under *Global Date and Time Filters*: Click *Add New Date/Time Filter* to create an all-day time filter for each country based on the average parent/caregiver-reported bedtime (as *Stop Time*) and wake-up time (as *On Time*) from the questionnaire. This will restrict the analysis to the specified waking time period on all day(s) as identified in the log diary file.

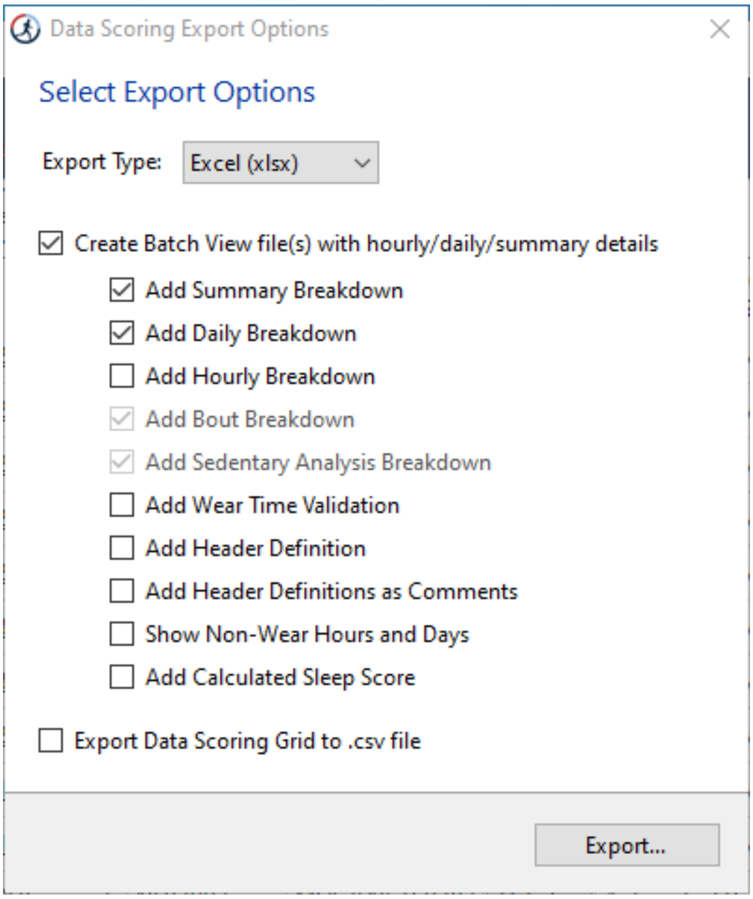


5.6 Click *Calculate* to continue with the analysis.

5.7 Click *Export* to export the results to an Excel (xlsx) document.

5.8 Tick the following output options: *Create Batch View file(s) with hourly/daily/summary details*, *Add Summary Breakdown* and *Add Daily Breakdown*.

8



5.9 Click *Export* and save the output file in the Country's folder created on the server (*Monitor Analysing -> Actigraph report*).

Step 6: Create a report based on the analysed output file

6.1 There are three spreadsheets created within the overall output file:

1) **Variables**: This sheet provides information about the cut-points and time filters applied to the analysis. Please add this to the country's finalised dataset ('*SUNRISEPILOT/MAIN_COUNTRYCODE_AG_Cutpoints*')

A	B	C	D	E
Cut Point Values				
Sedentary	0	to	799	
Light	800	to	1679	
Moderate	1680	to	3367	
Vigorous	3368	and above		
MVPA Minimum Count	1680			
Date and Time Filters				
Name	Date	Start Time	Stop Time	
TheNetherlands	All Days	7:00:00 AM	9:00:00 PM	

2) **Daily:** This sheet provides the analysed output for each valid day identified in the log diary per child ID. Please check and make sure that the valid time recorded for each day (refer to column AR 'Time') is >=360 minutes.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Subject	Filename	Epoch	Weight (lbs)	Age	Gender	Date	Day of Week	Day of Week Num	Sedentary	Light	Moderate	Vigorous	% in Sedenta
2	NL01001	NL01001 (2022-04-12)15sec.agd	15	0	0		12/04/2022	Tuesday	2	667	100	82	25.25	76.29%
3	NL01001	NL01001 (2022-04-12)15sec.agd	15	0	0		13/04/2022	Wednesday	3	671.5	118.75	94.5	27.25	73.63%
4	NL01001	NL01001 (2022-04-12)15sec.agd	15	0	0		14/04/2022	Thursday	4	746.75	71.75	56	24	83.11%
5	NL01002	NL01002 (2022-04-12)15sec.agd	15	0	0		12/04/2022	Tuesday	2	795.25	95.75	42.25	11	84.22%
6	NL01002	NL01002 (2022-04-12)15sec.agd	15	0	0		13/04/2022	Wednesday	3	747.25	107.25	56.75	15.5	80.63%
7	NL01002	NL01002 (2022-04-12)15sec.agd	15	0	0		14/04/2022	Thursday	4	730.25	146.25	96	19.75	73.60%
8	NL01003	NL01003 (2022-04-12)15sec.agd	15	0	0		12/04/2022	Tuesday	2	694.5	91.5	105.25	51.75	73.65%
9	NL01003	NL01003 (2022-04-12)15sec.agd	15	0	0		13/04/2022	Wednesday	3	753	99.75	88.25	41.5	76.64%
10	NL01003	NL01003 (2022-04-12)15sec.agd	15	0	0		14/04/2022	Thursday	4	656	91.25	78	61	74.02%
11	NL01004	NL01004 (2022-04-12)15sec.agd	15	0	0		12/04/2022	Tuesday	2	642	123.5	106.75	34	70.84%
12	NL01004	NL01004 (2022-04-12)15sec.agd	15	0	0		13/04/2022	Wednesday	3	753	111.5	107.25	36.25	74.70%
13	NL01004	NL01004 (2022-04-12)15sec.agd	15	0	0		14/04/2022	Thursday	4	663.75	123.5	87.5	20.25	74.16%
14	NL01005	NL01005 (2022-04-12)15sec.agd	15	0	0		14/04/2022	Thursday	4	645.5	117.5	94.75	26	73.04%
15	NL01005	NL01005 (2022-04-12)15sec.agd	15	0	0		15/04/2022	Friday	5	542.25	133.5	92.5	99	62.53%
16	NL01005	NL01005 (2022-04-12)15sec.agd	15	0	0		16/04/2022	Saturday	6	336	130.5	126	35.5	53.50%
17	NL01005	NL01005 (2022-04-12)15sec.agd	15	0	0		17/04/2022	Sunday	7	686.25	151.75	94.5	20	72.05%
18	NL01005	NL01005 (2022-04-12)15sec.agd	15	0	0		18/04/2022	Monday	1	649.5	155.75	143	29	66.46%
19	NL01006	NL01006 (2022-04-13)15sec.agd	15	0	0		13/04/2022	Wednesday	3	702.25	104.25	97	30.5	75.19%
20	NL01006	NL01006 (2022-04-13)15sec.agd	15	0	0		14/04/2022	Thursday	4	706	113.5	92	31.25	74.89%
21	NL01006	NL01006 (2022-04-13)15sec.agd	15	0	0		15/04/2022	Friday	5	685	119.25	117.75	49	70.55%
22	NL02002	NL02002 (2022-04-22)15sec.agd	15	0	0		22/04/2022	Friday	5	345.75	58.25	20	6	80.41%

Note: If a day is recorded as less than 360 minutes, delete that row of data and compute the average results for each ID manually.

3) **Summary:** This sheet provides the summary of the analysed output. The values shown are the sum of time spent in each behaviour across all valid days included in the analysis (i.e., the days reported in the Daily sheet). Please use this sheet of data for the final analysis only if the days included in the Daily sheet are all >=360 minutes as described above.

A	B	C	D	E	F	G	H	I	J	K	
Subject	Filename	Epoch	Weight (lbs)	Age	Gender	Sedentary	Light	Moderate	Vigorous	% in Sedentary	%
NL01001	NL01001 (2022-04-12)15sec.agd	15	0	0		2085.25	290.5	232.5	76.5	77.67%	1
NL01002	NL01002 (2022-04-12)15sec.agd	15	0	0		2272.75	349.25	195	46.25	79.38%	1
NL01003	NL01003 (2022-04-12)15sec.agd	15	0	0		2103.5	282.5	271.5	154.25	74.81%	1
NL01004	NL01004 (2022-04-12)15sec.agd	15	0	0		2058.75	358.5	301.5	90.5	73.28%	1
NL01005	NL01005 (2022-04-12)15sec.agd	15	0	0		2859.5	689	550.75	209.5	66.36%	1
NL01006	NL01006 (2022-04-13)15sec.agd	15	0	0		2093.25	337	306.75	110.75	73.51%	1
NL02001	NL02001 (2022-04-13)15sec.agd	15	0	0		0	0	0	0	0.00%	0.
NL02002	NL02002 (2022-04-22)15sec.agd	15	0	0		1476	179.25	82.25	13	84.32%	1
NL03001	NL03001 (2022-05-11)15sec.agd	15	0	0		1889.5	302.25	277	143.25	72.34%	1
NL03002	NL03002 (2022-05-11)15sec.agd	15	0	0		1686.5	407.5	434	228.25	61.19%	1
NL03003	NL03003 (2022-05-12)15sec.agd	15	0	0		2040.25	233.5	154.5	164.75	78.68%	9.
NL03004	NL03004 (2022-05-12)15sec.agd	15	0	0		2228.25	336.5	277.25	135.75	74.83%	1
NL03005	NL03005 (2022-05-11)15sec.agd	15	0	0		2236	392.75	382.25	266.5	68.22%	1
NL03006	NL03006 (2022-05-12)15sec.agd	15	0	0		1304.75	261.5	187.75	62	71.85%	1
NL03007	NL03007 (2022-05-12)15sec.agd	15	0	0		2065.25	312	237.75	118.75	75.55%	1
NL03008	NL03008 (2022-05-11)15sec.agd	15	0	0		2277.25	270.75	166.75	75.25	81.62%	9.
NL03009	NL03009 (2022-05-12)15sec.agd	15	0	0		2280.75	241	129	86.25	83.33%	8.
NL03010	NL03010 (2022-05-12)15sec.agd	15	0	0		2257.25	236.75	108	49.5	85.13%	8.
NL03011	NL03011 (2022-05-11)15sec.agd	15	0	0		2114	307	267.75	136	74.84%	1
NL03012	NL03012 (2022-05-12)15sec.agd	15	0	0		2147	326.5	214.75	62.25	78.06%	1
NL03013	NL03013 (2022-05-17)15sec.agd	15	0	0		2219	360.5	209.5	58.75	77.92%	1
NL03014	NL03014 (2022-05-17)15sec.agd	15	0	0		1873	327	283.25	158.75	70.89%	1
NL03016	NL03016 (2022-05-17)15sec.agd	15	0	0		2314.5	313.25	196.5	62.5	80.18%	1
NL03017	NL03017 (2022-05-21)15sec.agd	15	0	0		2114	371.75	384.75	0	73.65%	1
NL04001	NL04001 (2022-06-02)15sec.agd	15	0	0		2090.75	243.5	117.75	26.5	84.36%	9.
NL04002	NL04002 (2022-06-02)15sec.agd	15	0	0		2270.75	306	171.25	58.5	80.91%	1
NL04003	NL04003 (2022-06-02)15sec.agd	15	0	0		1874.25	230.5	122.25	32.5	82.95%	1
NL04004	NL04004 (2022-06-02)15sec.agd	15	0	0		2310.25	292.5	192	65	80.79%	1
NL04005	NL04005 (2022-06-02)15sec.agd	15	0	0		2213	279	230.75	0	81.28%	1
NL05001	NL05001 (2022-05-31)15sec.agd	15	0	0		1817.75	228	153.25	85.25	79.58%	9.
NL05002	NL05002 (2022-05-31)15sec.agd	15	0	0		1981	371.5	223.5	65	75.01%	1
NL05003	NL05003 (2022-05-31)15sec.agd	15	0	0		1994.25	312.75	298.25	154.25	72.27%	1
NL05004	NL05004 (2022-05-31)15sec.agd	15	0	0		2125	348.5	237	81.25	76.12%	1
NL05005	NL05005 (2022-05-31)15sec.agd	15	0	0		2100.75	314.5	227.75	91.5	76.82%	1
NL05006	NL05006 (2022-05-31)15sec.agd	15	0	0		1433.5	329.75	343	184.75	62.57%	1

Variables | Daily | **Summary**

10

6.2 Create a new sheet reporting the variables of interests based on data from the Summary sheet (or Daily Sheet if a day has to be removed due to having less than 360 minutes of valid wear time) and log diary. Please add this to the country's finalised dataset (*'SUNRISEPILOT/MAIN_COUNTRYCODE_AG_Actigraph'*).

The variables include:

i. ChildID (from Column A – Subject)
ii. ag_Filename (from Column B – Filename)
iii. ag_ondate (from log diary file – On Date column)
iv. ag_offdate (from log diary file – Off Date column)
v. ag_valid_days (from Column AP – Calendar Days)
vi. ag_average_valid_weartime (from Column AO – Time; then divide it by ag_valid_days)
vii. ag_average_SED (from Column G – Sedentary; then divide it by ag_valid_days)
viii. ag_average_LPA (from Column H – Light; then divide it by ag_valid_days)
ix. ag_average_MPA (from Column I – Moderate; then divide it by ag_valid_days)
x. ag_average_VPA (from Column J – Vigorous; then divide it by ag_valid_days)
xi. ag_average_MVPA (from Column Q – Average MVPA per day)
xii. ag_average_TPA (sum of ag_average_LPA and ag_average_MVPA)
xiii. ag_meeting_60mins_MVPA ('1' if ag_average_MVPA >=60, otherwise '0')
xiv. ag_meeting_180mins_TPA ('1' if ag_average_TPA >=180, otherwise '0')
xv. ag_meeting_MVPA_and_TPA_recommend ('1' if ag_meeting_60mins_MVPA and ag_meeting_180mins_TPA are both recorded as '1', otherwise '0')

6.3 In addition to the data columns as described above, please include a data row that provides the average values for each variable at the country level:

E	F	G	H	I	J	K	L
ag_valid_da	ag_average_	ag_average_SE	ag_average_LPA	ag_average_MP	ag_average_VP/	ag_average_MVF	ag_average_TPA
3	828	678	67	56	27	83	150
3	780	634	85	49	13	61	146
	Mean values	**603**	**99**	**71**	**22**	**93**	**192**

And include a summary section that provides the following information:

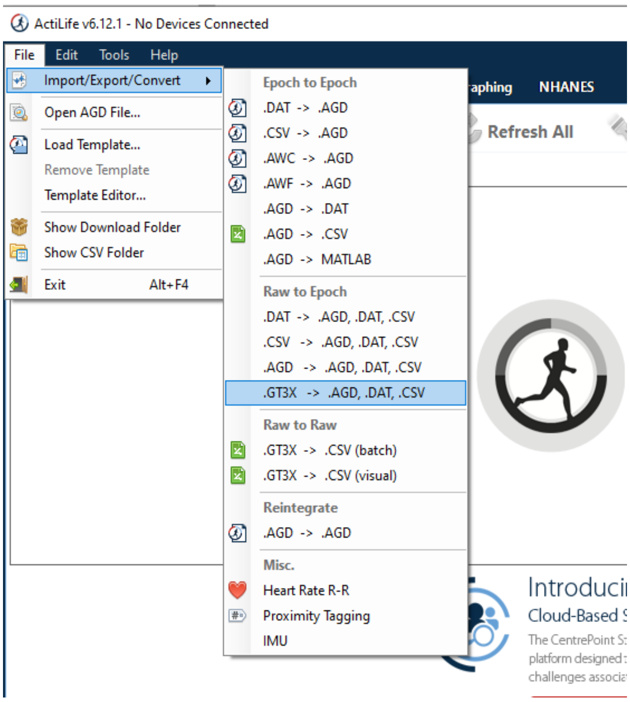
i. With 24h data (i.e., the number & percentage of children with 1 valid day of data as indicated in the ag_valid_days column)
ii. With 48h data (i.e., the number & percentage of children with 2 valid days of data as indicated in the ag_valid_days column)
iii. With 72h data (i.e., the number & percentage of children with 3 valid days of data as indicated in the ag_valid_days column)
iv. With >72h data – optional (i.e., the number & percentage of children with > 3 valid days of data as indicated in the ag_valid_days column)
v. Meeting 60 mins of MVPA/d (i.e., the number & percentage of children who met the MVPA guidelines as indicated in the ag_meeting_60mins_MVPA column)
vi. Meeting 180 mins of total PA/d (i.e., the number & percentage of children who met the TPA guidelines as indicated in the ag_meeting_180mins_TPA column)
vii. Meeting MVPA+TPA recommendations (i.e., the number & percentage of children who met both the MVPA and TPA guidelines as indicated in the ag_meeting_MVPA_and_TPA_recommend column).

SUMMARY	Number	Percentage
With 24h data	3	3.2
With 48h data	8	8.4
With 72h data	84	88.4
Meeting 60 mins of MVPA/d	86	90.5
Meeting 180 mins of total PA/d	58	61.1
Meeting MVPA+TPA recommendations	58	61.1

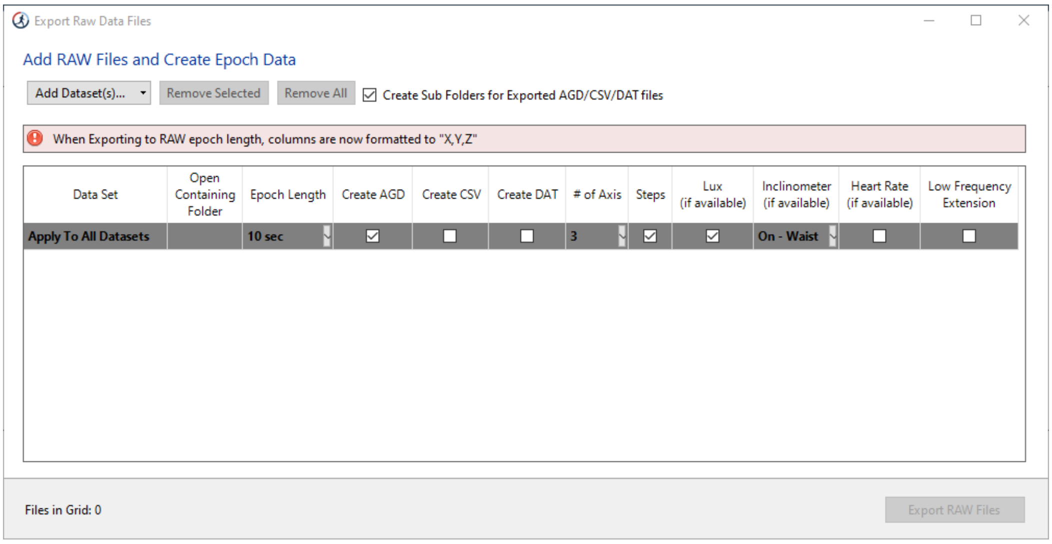
<u>Others:</u>

1. How to re-export the data file into different epoch length?
   To do this you will need to have the .gt3x data file, which contains the raw accelerations data (i.e., unprocessed).

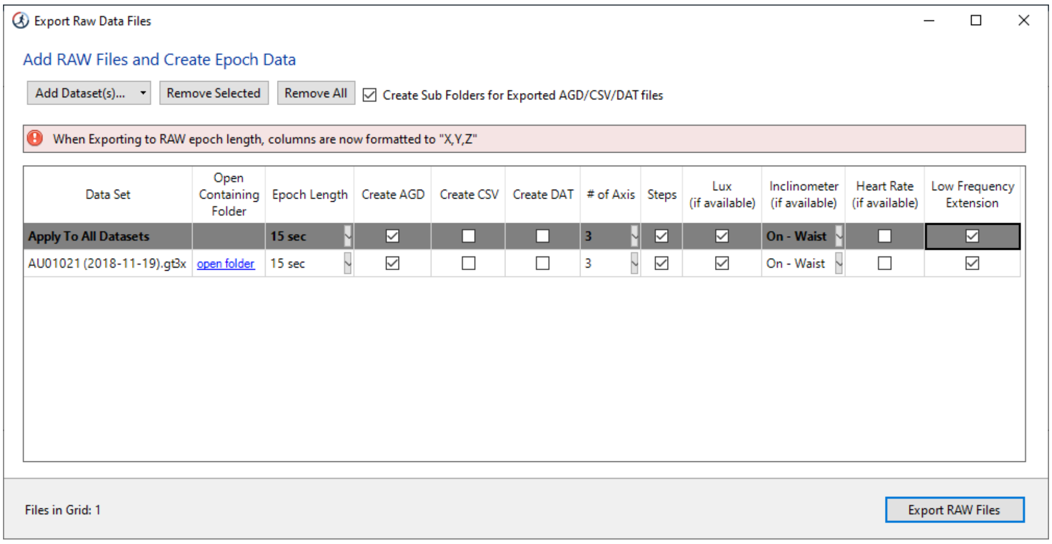
   1.1 Open the ActiLife software. Click on *File* and then *Import/Export/Convert*. You will see a list of options. Select *'GT3X -> .AGD, .DAT, .CSV'* under *Raw to Epoch* section.



   1.2 A new window will appear for you to add the data file(s) that you wish to convert/export into the specified epoch length in different file formats.



1.3 Click *Add Dataset(s)* to import the gt3x file. Once the data file has been imported, it will appear on the screen under *Data Set* column. For SUNRISE study, the data should be exported into 15 sec epoch length in the AGD file format. Please also make sure to select "3" under *# of Axis column* and tick the *Steps, Lux, Inclinometer (On-Waist)* and *Low Frequency Extension* columns. If you wish to store the exported files in a separate folder, tick *'Create Sub Folders for Exported AGD/CSV/DAT files'*.



1.4 Click Export RAW Files to start the exporting process. Once this is done, you will be able to find the exported .agd file in the data file folder where the gt3x file was stored.

13

Appendix K: University of Malawi Research Ethics Committee approval letter

UNIVERSITY OF MALAWI

ACTING PRINCIPAL
Prof. Samson Sajidu, BSc Mlw, MPhil Cantab, Ph.D Mlw

CHANCELLOR COLLEGE
P.O. Box 280, Zomba, Malawi

Telephone: (265) 524 222
Fax: (265) 524 046
E-mail: principal@cc.ac.mw

Our Ref: P.05/21/65
Your Ref:

10th June 2021

Mr. Tawonga Mwase-Vuma
Centre for Social Research
Chancellor College
Box 280,
Zomba,

Email: tmwase-vuma@cc.ac.mw

Dear Mr. Mwase-Vuma

RESEARCH ETHICS AND REGULATORY APPROVAL AND PERMIT FOR PROTOCOL NO. P.05/21/65 MOVEMENT BEHAVIOURS IN EARLY CHILDHOOD IN MALAWI

Having satisfied all the relevant ethical and regulatory requirements, I am pleased to inform you that the above referred research protocol has officially been approved. You are now permitted to proceed with its implementation. Should there be any amendments to the approved protocol in the course of implementing it, you shall be required to seek approval of such amendments before implementation of the same.

This approval is valid for **one year** from the date of issuance of this approval. If the study goes beyond one year, an annual approval for continuation shall be required to be sought from the University of Malawi Research Ethics Committee (UNIMAREC) in a format that is available at the Secretariat.

Once the study is finalized, you are required to furnish the Committee and the Principal with a final report of the study. The Committee reserves the right to carry out compliance inspection of this approved protocol at any time as may be deemed by it. As such, you are expected to properly maintain all study documents including consent forms.

Wishing you a successful implementation of your study.

Yours Sincerely,

UNIVERSITY OF MALAWI
RESEARCH ETHICS COMMITTEE
10 JUN 2021
APPROVED
P.O. BOX 280, ZOMBA

Prof. Alister Munthali
CHAIRPERSON OF UNIMAREC

CC: Principal
Vice Principal
Registrar
College Finance Officer
Dean of Research
Compliance Officer

ACTING PRINCIPAL
Prof. Samson Sajidu, BSc Mlw, MPhil Cantab, Ph.D Mlw

CHANCELLOR COLLEGE
P.O. Box 280, Zomba, Malawi

Our Ref: P.05/21/65
Your Ref:

Telephone: (265) 524 222
Fax: (265) 524 046
E-mail: principal@cc.ac.mw

28th June 2022

Mr Tawonga Vuma Mwase
Centre for Social Research
University of Malawi
P.O. Box 280,
Zomba.

tmwase-vuma@cc.ac.mw

Dear Mr Mwase

RESEARCH ETHICS AND REGULATORY ANNUAL CONTINUATION APPROVAL FOR PROTOCOL NO. P.05/21/65. MOVEMENT BEHAVIOURS IN EARLY CHILDHOOD IN MALAWI

The University of Malawi Research Ethics Committee (UNIMAREC) reviewed your submission for an annual continuation to the above-referred protocol.

Overall, the committee noted good research progress and hereby grants you a research ethics annual continuation approval and regulatory permit. This approval is valid for one year from the date indicated above. Should the study go beyond one year, you will be required to apply for annual review and continuation on the form available at the committee secretariat before the expiry date of this approval.

Wishing you a successful implementation of the study and the committee awaits a copy of the written technical report.

UNIVERSITY OF MALAWI
RESEARCH ETHICS COMMITTEE
29 JUN 2022
APPROVED
P.O. BOX 280, ZOMBA

Yours sincerely,

Prof Alister C. Munthali
CHAIRPERSON OF UNIMAREC

CC: Vice Chancellor
Acting University Registrar
Finance Officer
Dean of Research
Head of Sociology Department
UNIMAREC Administrator
UNIMAREC Compliance Officer

Appendix L: Figure illustrating additional measurements collected as part of the SUNRISE International Study

Figure illustrating motor and cognitive development assessment procedures in Malawian children according to the SUNRISE International Study protocol. (A) Child performing the supine-timed up and go test with the data collector to assess mobility and posture. (B & C) Children engaging with the 9-hole pegboard to assess fine motor skills. (D & F) Children completing cognitive assessment tasks (Mr. Ant and Go/No-Go tests) on iPads. (E) Data collector supporting a child to hold a handgrip dynamometer for assessing upper extremity strength. (G) Child performing the one-legged standing balance test with the data collector to assess posture and balance. The author is seen in photos D, E, and F. (Photo credits: SUNRISE Malawi, 2022-2023. Image composition by the author.)

Appendix M: Supplementary material for submitted manuscript for Chapter 5

Supplementary File 1

Table A: Summary data for ActiGraph accelerometry-measured habitual time spent in TPA and MVPA.

	Number	Mean (SE)
Accelerometer TPA, min/day	372[a]	264.5 (6.0)
Accelerometer MVPA, min/day	372[a]	119.4 (3.3)

Notes: a denotes participants with accelerometry data for 3 valid days; min/day = minutes per day; TPA = total physical activity; MVPA = moderate-to-vigorous physical activity; SE = standard error

Table B: Proportion of meeting the global guideline on physical activity based on accelerometry-measured activity counts (min/day).

	Number	%	95% CI
Meeting TPA by min/day [a]	342	90.9	86.9, 95.2
Meeting MVPA by min/day [a]	363	97.6	94.3, 99.0
Meeting TPA (including MVPA) guideline by min/day [a]	300	92.3	86.3, 95.8
Meeting three 24-hour movement guidelines [b]	220	59.7	43.8, 73.7
Meeting all 24-hour movement guidelines [b]	180	48.8	36.2, 61.5

Notes: a denotes n=368; b denotes sub-population with data on both parent-reported and accelerometry-measured outcomes (n=369); TPA = total physical activity; MVPA = moderate-to-vigorous physical activity. Meeting three 24-h movement guidelines was defined as parent-reported sedentary screen time of ≤60 min/day, at least 10-13 hours/day for sleep duration, and 180 min/day of TPA including 60 min/day of MVPA. Meeting all four 24-h movement guidelines was defined as parent-reported restrained sitting of no more than 1 hour at a time, ≤60 min/day for sedentary screen time, at least

Supplementary File 2

Published protocol paper	Deviations from the protocol paper
Children will be asked to wear ActiGraph accelerometers for 5 consecutive days, including during sleep and water-based activities (such as bathing and swimming).	Children wear asked to wear ActiGraph accelerometers for five consecutive 24-hour periods except during water-based activities (such as bathing/showering, or swimming). While the published protocol paper indicates that children wear ActiGraph accelerometers including during water-based activities (https://doi.org/10.1136/bmjopen-2021-049267), the Malawi study followed the SUNRISE accelerometry protocol manual that states otherwise. This has also been the case with all other countries that implemented the SUNRISE protocol (see Hossain et al. 2021 SUNRISE Bangladesh https://doi.org/10.1186/s40814-021-00912-1; Kim et al. 2022 SUNRISE Vietnam https://doi.org/10.1007/s12098-021-03895-2; Byambaa et al. 2024 SUNRISE Mongolia https://doi.org/10.1123/jpah.2023-0511; Abdeta et al. 2024 SUNRISE Ethiopia https://doi.org/10.1186/s44167-024-00060-w)
A sample size of 1000 healthy children aged 3-4 years per country, with equal numbers (500 each) from urban and rural settings (page 3). The protocol further required that "the sample is broadly representative of the country in terms of sex, socioeconomic backgrounds of parents, and urban/rural residence" (page 7).	Our sample comprised 417 3-4 year olds (51.5% girls), and the majority of children (n=317; 76%) were recruited from rural ECEC centers. While our sample deviated from the SUNRISE protocol, this was based on what was funded. Oversampling from rural ECEC centres allowed a sample size that is broadly reflects the urban/rural population distribution and socioeconomic backgrounds in Malawi (i.e., the majority of Malawians [85%] live in

Notes: 1. National Statistical Office. 2018 Malawi Population and Housing Census Report [Internet]. Zomba, Malawi; 2019 [cited 2024 Jun 26]. Available from: https://malawi.unfpa.org/en/publications/malawi-2018-population-and-housing-census-main-report 2. Government of Malawi. The second Malawi multidimensional poverty index report [Internet]. Zomba, Malawi; 2022 [cited 2024 Jun 26]. Available from: https://www.undp.org/malawi/publications/second-malawi-multidimensional-poverty-index