UNIVERSITY OF STRATHCLYDE

A Biomechanical Evaluation of the Miami J® Advanced cervical collar

MSc Bioengineering

Dissertation

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Acknowledgements

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Abstract

The work presented in this dissertation details the biomechanical evaluation, on healthy volunteers, of wearing a cervical collar.

Spinal neck injuries can be serious and may need to be treated with orthoses. Cervical (neck) collars are prescribed to patients with symptoms ranging from minor muscle spasm to serious instability, to immobilize the neck and also to relieve muscle strain. For the collar to work as expected it needs to be rigid enough to prevent the spine from misaligning and to protect the injury site, but at the same time it needs to be comfortable and breathable [1, 2, 5].

Despite common place use, there is a lack of biomechanical assessment on people wearing a cervical collar.

The purpose of this project is to assess the effect of wearing a cervical collar on the functional ability of healthy volunteers. Functional ability impairment was investigated using Vicon plug-in-gait and a force plate to investigate postural stability. Functional ability assessments; stand to sit, sit to stand, gait analysis, and functional stability was made with and without the collar for comparison. Also, eyes condition (eyes open, eyes closed) was analysed and compared for the postural stability part of this study.

The results identified significant difference in the ankle movement during gait (less than 2° angle reduction when wearing a collar), but did not identify any significant difference for joint movement in hip and knee. Differences were identified between hip trials for hip maximum peak and hip ROM.

For the sit to stand and stand to sit activity no significant difference was identified when collar condition was compared. However a significant difference between trials concerning peak hip flexion was observed.

Postural stability measures showed no significant differences due to wearing a collar. However, there was a trend that the length of the COP path, and the velocity of the COP,

decreased by wearing a collar ($p < 0.1$). As expected, and in agreement with literature, shutting the eyes increases the length of the trace of COP travelled ($p < 0.01$), increased the speed of the COP travel ($p < 0.01$) and increased the sway area ($p = 0.01$). Finally, there is a significant interaction between wearing a collar and shutting the eyes regarding sway area. With the collar off, a large difference in sway area is seen between the eyes open and eyes closed conditions (with the eyes closed having a greater sway), but wearing a collar reduces this difference.

Our results suggest that immobilising the neck joint reduces the degrees of freedom of the balance mechanism, and does not have a negative effect on postural stability in the healthy population.

1. Introduction

Biomechanical assessments of people wearing a cervical collar in order to assess the effect of a neck collar on balance and functional ability are scarce. This dissertation will address the issues of functional ability and postural stability of healthy people with an immobilized neck.

1.1 Neck collars

Spinal neck injuries can be serious and may need to be treated with orthoses and sometimes surgery if the patient fails to show improvement with a non-surgical treatment. Cervical (neck) collars are prescribed to patients with symptoms ranging from minor muscle spasm to serious instability, to immobilize the neck and also to relieve muscle strain. The collar is used to relieve pain, correct spinal deformity and misalignment, maintain specific spinal posture, as well as protect the neck from damaging stresses. For the collar to work as expected it needs to be rigid enough to prevent the spine from misaligning and to protect the injury site, but at the same time it needs to be comfortable and breathable [1, 2, 5]. If the injury does not require immobilisation, a soft foam collar can be more suitable.

1.1.1 Types

Various types of cervical collars are on the market today for cervical injury treatment. The kind of support which is needed depends on the injury or trauma incurred. If a person needs greater immobilisation after a serious accident, e.g. a whiplash, a stiff cervical collar would be a collar of choice. Collars that offer a high immobilisation are, for example, Philadelphia® or Miami J® from Össur, and Vista® or Aspen® from Aspen. They are either height adjustable or come in different sizes.

For minor cervical injuries, and for stress release or a neck pain, soft collars would be more suitable for the patient to limit head motion. They are made of firm, medium or soft density foam to provide a support that is comfortable but not as restricted. Types on the market are, for example Universal and Foam cervical collar, both from Össur.

The researchers were kindly given a Miami J Advanced Cervical Collar (Össur, Iceland) for this investigation, and the following work concerns this particular collar.

1.1.2 Indications for use

A Miami J Advanced cervical collar is the collar of choice given one of the following indications [7]:

- Post trauma
- Stable cervical fractures
- Cervical Spondylitis
- Motor neuron disease
- Rheumatiod arthritis and Osteoarthritis cervical spine
- Herniated cervical disk
- Post-operative

1.1.3 Neck kinematics in the healthy population

There are various measuring methods to evaluate the range of motion in the neck, such as; CA 6000 Spine Analyzer [19], Cervical range of motion goniometer (CROM) [20, 21, 22] radiographic method [21], uniplanar goniometer [22], chin-sternal distance [22], visual estimation [20], universal goniometer (UG) [20].

It is the cervical spine that allows the head to flex, extend, rotate, and bend laterally. Head movement range of motion depends on the structure and shape of the cervical vertebrae and how they interact. Thus, the cervical spine´s kinematics is based on the anatomy of the bones in the neck and the formed joints [18].

Usually when the range of motion in the neck is analysed, certain movements are usually observed; flexion and extension in the sagittal plane is measured, as well as the lateral bending to right and left in the frontal plane, and finally the neck´s rotation [18]. See figure 1 below. Usually a Goniometer is used to measure the range of motion. Studies on how much a collar restricts a neck motion to compare neck kinematics with and without a collar usually use these same movements.

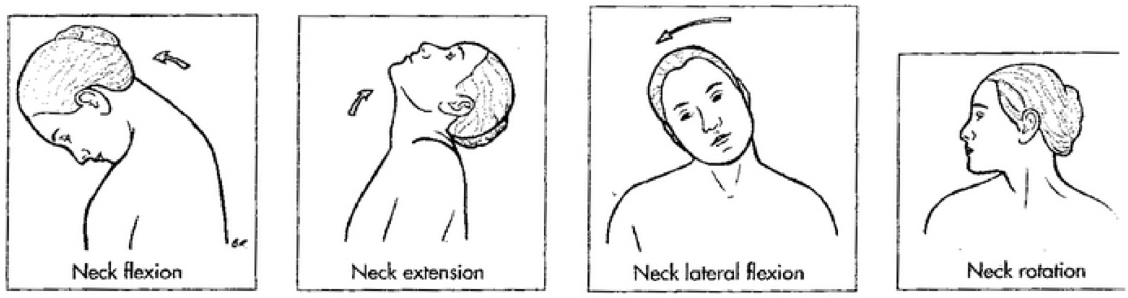


Figure 1. Neck motion range

The cervical spine consists of seven vertebral segments (C1-7), which connects the skull base and the thoracic spine. Because of its unusual shape, a great deal of stresses and forces can be applied to the cervical spine at any time, even during normal daily activities.

Early studies on the cervical spine have examined the range of motion in the neck, flexion and extension [18]. Some of the older studies used cadavers to explore the neck motion, which can give inaccurate results because there is no muscle function. Even so, it helps investigators to know what they might expect and how segments should be measured before in vivo studies are performed [18].

Previous neck motion study measured the range of motion between the head and the first thoracic vertebrae using CA 6000 Spine Analyzer. 250 volunteers were recruited, age range 14-70 [19]. Average range of motion in the sagittal plane was 122° with flexion seeming to be more important than extension. Average bending range of motion was 88° with right bending comparable to left bending. In the transverse plane, the global rotation range of motion was 144° with no significant differences between the left and right rotations. When rotating the head from flexed head position, the global range of motion was 134°, not far from the motion range in the neutral flexion. Results showed a reduction in the range of motion for older subjects, whilst gender had no effect on the motion range (table 1) [19].

Table 1

Mean (SD) of primary cervical motion ranges in degrees				
	Total	14-19 yr (N = 68)	20-29 yr (N = 133)	30-70 yr (N = 49)
Flexion-extension				
Flexion	65 (11)	70 (10)	66 (10)	57 (11)
Extension	57 (17)	61 (14)	57 (15)	50 (15)
Total	122 (18)	131 (15)	123 (16)	107 (16)
Lateral bending				
Right	44 (9)	48 (10)	45 (8)	39 (9)
Left	44 (8)	47 (9)	44 (7)	38 (7)
Total	88 (16)	95 (16)	89 (14)	77 (15)
Rotation (neutral)				
Right	66 (12)	67 (12)	67 (11)	63 (12)
Left	69 (13)	70 (14)	69 (12)	66 (11)
Total	134 (24)	137 (24)	134 (21)	128 (28)

Table 1. Results from Feipel V et al. 1999 [19]

An early study compared the cervical range of motion using a goniometer (CROM) with the radiographic method. [21] Thirty-one healthy volunteers within age range 18-45, were recruited. Participants sat on a stool and the goniometer was positioned on their head. The first ROM measurement was taken when participant was in neutral position. The radiograph was obtained immediately after. Fully flexed and extended neck motion was measured with both methods and then compared. A high correlation existed between the two methods and thus, the CROM goniometer was found to be a valid measuring tool for range of motion in the neck [21].

A study on how neck dimension affects the cervical range of motion, recruited 100 participants in the age range 20-40 to take part in a simple experiment [22]. They were recorded with respect to gender, age, and ROM in three planes. Two neck motion measuring methods, uniplanar goniometer, and chin-sternal distance, were evaluated against CROM goniometer, which is a validated neck motion method.

Figure 2. CROM goniometer

By doing multiple linear regression analysis they were able to determine that the lateral flexion was related most closely to the ratio of perimeter and the neck length, while the flexion in the sagittal plane and the lateral rotation was only related most closely to the neck perimeter. Thus, this study showed the importance of taking the neck perimeter into account when neck ROM is measured since it is one of the factors that influence the motion range.

Table 2

Cervical ROM of 100 healthy individuals using the CROM goniometer (in degree)

Movement	ROM (mean, SD, range)	ROM (mean, SD, range)	Distance (in cm) (mean, SD, range)
	CROM goniometer	Handheld goniometer	Chin-chest distance
Flexion-extension	125 ± 19.3, 61-166	121.8 ± 29.8, 56-174	17.1 ± 2.58, 10.5-27.5
Lateral flexion	79.8 ± 15.1, 57-130	78.2 ± 41.9, 48-140	
Rotation	131 ± 15.6, 100-172	126.0 ± 51.7, 80-174	

Table 2. Results from Reynolds J. et al.2009 [22]

By comparing the results using these three different measuring methods, uniplanar goniometer and chin-sternal distance were found not to be reliable enough to compare two similar groups for range of motion in the neck (table 2). The investigator considered that the uniplanar goniometer should only be used as a screening tool for lateral flexion and sagittal ROM screening. Range of motion measured with the validated measuring method, CROM, was 125° for flexion-extension, 79.8° for lateral flexion, and 131° for rotation [22].

Another measuring tool comparison study was performed to compare the accuracy and reliability of visual estimation, universal goniometer (UG) and tape measurement methods to measure the range of motion in the cervical spine [20]. One hundred healthy volunteers were recruited to measure neck flexion, extension, left, and right lateral bending, and finally neck rotation. The cervical range of motion goniometer (CROM) was compared to the other methods. The UG was the most accurate one when it was aligned on a fixed landmark. The next most accurate was the same goniometer, UG, aligned on an anatomic landmark. The visual estimation and the tape measurement measured the range of motion inaccurately [20].

As previous studies have shown, the best and most accurate way to measure the range of motion in the neck, is using the radiographic method or the cervical range of motion goniometer. Using radiographic method is impractical and expensive and thus, the CROM is the best way to go [21, 20]. Another study identified reduced ROM for older subjects compared to younger subjects and found no gender effect [19]. Another study [22] proved the importance of taking neck perimeter into account when measuring neck ROM using CROM goniometer.

1.1.4 Neck kinematics whilst wearing a collar

Previous functional ability studies on volunteers wearing a cervical collar have used various measuring tools to evaluate neck movement or the range of motion (ROM) while wearing a collar such as; Myrin goniometry [12], Electromagnetic sensors [3], Electrogeniometer and a Tosiometer measuring system [4], and a plug-in-gait Vicon system [2].

Immobilising cervical collar is othoses of choice for patients that need neck restriction. The collar is supposed to prevent further spinal misalignment by keeping the head and neck upright and as steady as possible. Previous studies on cervical collar comparisons have all shown reduction in neck joint motion, but this varies between different collars.

A twenty year old study observed if the Airflow cervical collar was rigid enough to restrict motion in the neck using a Myrin goniometer [12]. Results showed a significant effect on the neck movement whilst wearing the collar. Ten young volunteers were recruited for this study. Flexion and extension were restricted but the lateral movement was not. They concluded this collar to be a valid tool for therapy [12].

In a study to evaluate how different anterior cervical collar heights restrict range of motion during daily activities, a Electrogeniometer and Torsiometer measuring system was used. It is a dynamic motion analysis system that allows calculation of the flexion, extension etc. The conclusion was that greater cervical collar height better restricts the ROM during daily activities such as walk, stand to sit and putting on socks. Even though increased collar height restricts the ROM better it does not mean it is better for the patient. By increasing the height too much can extend the neck and thus, can cause skin issues were the collar is under too much pressure, at the chest and/or the jaw. It is best to choose a collar height as great as possible, or up to a point before it hyperextends the neck [4]. It is important to fit the collar correctly so it does not damage the clinical outcome [3].

Another study recruited volunteers for a functional ability evaluation using Vicon plug-in-gate [2]. 3D kinematic data was collected by performing three trials in each of the 15 test conditions wearing no collar and four different cervical collars and performed three different head movements: flexion-extension, left-right lateral flexion, and left-right axial rotation. The result showed that two of the collars, Miami J and C-Breeze showed much greater reduction on ROM in flexion than the XTW collar. For lateral and extension bending, all three collars showed a greater reduction than the Miami J collar, and C-Breeze showed a greater reduction than Miami J in axial rotation. See table 3 below [2].

Table 3				
Average ROM (deg) during the cervical movements: mean (standard deviation)				
Brace	Flexion	Extension	Lateral flexion	Rotation
Unbraced	56.0 (7.2)	68.6 (12.9)	83.5 (11.2)	137.4 (15.4)
Miami J	8.5 (7.8)	31.1 (16.7)	51.5 (14.6)	48.2 (22.4)
C-Breeze	9.6 (7.1)	27.2 (15.7)	46.3 (15.1)	42.0 (17.8)
Aspen	11.6 (10.5)	26.2 (16.2)	46.6 (14.9)	45.0 (20.5)
XTW	12.5 (8.9)	23.0 (13.8)	45.3 (14.7)	44.1 (20.1)

Table 3. Results from Songning Zhang et al. 2005 [2]

A comparison study from 1990 showed that the Miami J® and NecLoc® cervical collars from Össur restrict the range of motion (ROM) in the neck more than the other collars (table 4) [16]. A CROM Goniometer was used to measure the neck motion in this study. Before the collars were used, the average ROM was measured and data were normalised to this value.

Table 4				
Collar	Flexion	Extension	Lateral Tilt	Rotation
Soft Foam	70%	73%	87%	78%
Philadelphia	26%	41%	71%	51%
Stifneck	27%	37%	49%	35%
NecLoc	14%	22%	35%	21%
Miami J	15%	25%	37%	24%

Table 4. Results from Thomas B. Ducker 2011 [16]

Table 4 shows that NecLoc and Miami J restrict the neck motion the most, or 14-15% in flexion, 22-25% in extension, 35-37% in lateral bending, and 21-24% in rotation [16].

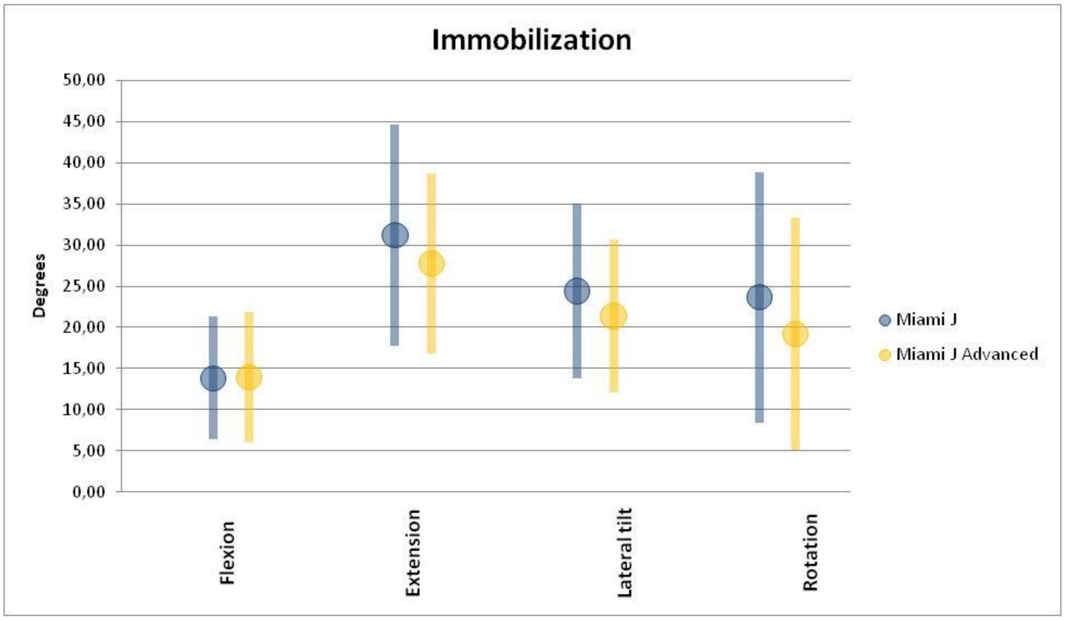
Another cervical collar comparison study from 2001 shows almost the same result for Miami J and Philadelphia (table 5). Again CROM Goniometer was used to measure the motion in the neck, the same as the previous study used [17].

Table 5				
Collar	Flexion	Extension	Lateral Tilt	Rotation
Miami J	16%	27%	38%	19%
Aspen	30%	40%	54%	29%
Philadelphia	26%	40%	53%	32%

Table 5. Results from Robert Mosenkis 2001 [17]

All of these collars restricted motion in the neck but they varied by how much. According to these results, the Miami J collar restricts the neck motion better than the Aspen and Philadelphia.

The Miami J Advanced, the collar of choice for this study, is confirmed to restrict ROM even better than collars mentioned before [33]. A study performed for the company Össur identified a significant restriction difference between Miami J Advanced and Miami J. using Goniometer. The MAYO study protocol and the Greenhouse-Geisser correlation was used to do a univariate repeated measures analysis of variance, and concluded that there was greater restriction in the lateral and rotation movement using Miami J Advanced compared to Miami J. Restriction for flexion and extension movement was the same for both cervical collars. See graph 1 and tables 6 and 7 below [33].



Graph 1. Immobilization comparison graph between Miami J and Miami J Advanced [33]

Table 6. Flexion, Extension, Lateral Tilt, Rotation

	Flexion	Extension	Lateral Tilt	Rotation
Miami J	13.8 ± 7.4	31.2 ± 13.4	24.4 ± 10.6	23.7 ± 15.2
Miami J Advanced	14.0 ± 7.9	27.7 ± 10.9	21.4 ± 9.3	19.2 ± 14.1

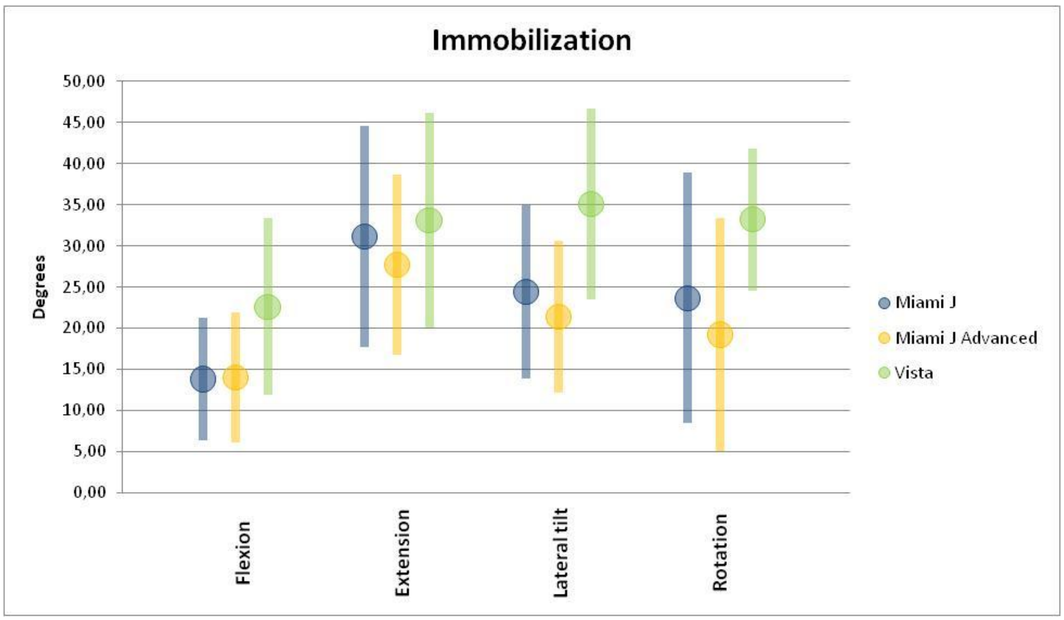
Table 6. Range of motion degrees wearing Miami J and Miami J Advanced [33]

Table 7. Comparison and significance of difference between Miami J and Miami J Advanced

Flexion		Extension		Lateral Tilt		Rotation	
P	Sign.	P	Sign.	P	Sign.	P	Sign.
0.994	No	0.128	No	0.049	Yes	0.057	Yes

Table 7. Significant difference between Miami J and Miami J Advanced [33]

Another study using a competitor´s collar for comparison identified a significant difference in the range of motion in the neck [33]. Fifteen volunteers were recruited for this experiment and they asked to wear three different collar, Miami J, Miami J Advanced, and then the competitors collar Vista. Results concluded significant differences in the lateral bending between all of the collars where Miami J Advanced restricted the movement the most but Vista restricted the least. The results for the rotation movement showed significant difference between Miami J and Miami J Advanced with the Miami J Advanced restricting the movement more. There was a strong indication that the Vista collar restricted less than the Miami J Advanced collar. For the motion range in the sagittal plane, flexion and extension, the results showed no significant difference between Miami J and Miami J Advanced, but both of those collars restricted the flexion motion significantly better than Vista. No significant difference between all three of them was identified for extension restriction. See graph 2 below [33].



Graph 2. Immobilization comparison graph between Miami J, Miami J Advanced and Vista [33]

In summary the studies mentioned in this chapter have focused on how a collar affects the neck´s range of motion. Ill fitted cervical collar increases range of motion [3], greater collar height restricts ROM better [4], and Miami J reduces ROM better in flexion than XTW, Philadelphia, and Aspen cervical collars [2, 16, 17]. The comparison studies between the Miami J Advanced, Miami J and Vista concluded greater neck motion immobilization wearing Miami J Advanced [33].

1.2 Functional ability

Functional ability tests evaluate the joint motion during various activities such as; sit-stand-sit manoeuvres, gait, and stair climbing these tests can give us important information for clinicians and patients before use, as well as for manufacturers to be able to improve their treatments and products. The investigator is only aware of one previous study on the functional ability of individuals wearing a cervical othosis [29].

1.2.1 Functional ability of the healthy population

A biomechanical and muscular activity study recruited ten subjects to perform a simple sit to stand activity [31]. Sagittal plane was observed for kinematic data collection as well as leg muscle activity, and ground reaction force. During the activity, COM transferred forward and then up. When subjects were rising, the upper body added to the COM velocity in the horizontal direction during forward body rotation. Leg extension added to the COM velocity in the vertical direction. Rather high moments around the knee occurred right after seat-off when knee and hip are extending. This high knee moment is provided to steer the GRF to some extent in the posterior direction [31].

A comparison study between biomechanics of sit to stand and sit to walk movement, as well as initiated gait, was performed using 3D motion capture system and force plates [26]. Nine young men were recruited for this study to obtain kinetic and kinematic data for evaluation. Results identified the maximum velocity in the horizontal plane, in the arm, head and trunk (HAT) did not happen at the same time in sit to walk and sit to stand (significantly later in sit to walk). In the sit to walk there was identified a higher maximum horizontal velocity of HAT and COG right before seat off in the sit to walk compared to sit to stand. At heel strike, they identified significantly difference between sit to walk and gait initiation. The AP ground reaction force (GRF) peak value was greater in the sit to walk. During sit to walk, the centre of gravity moved in front of the support base. The investigators conclude that sit to walk movement is not a stable motion and thus, balance is needed to perform this activity. Horizontal velocity of HAT and COG needs to be greater at seat off to create an impulsive force in the sit to walk activity. At first heel strike, the horizontal force produced by the movement in the trunk, arms and head is suppressed [26].

A previous study analysed how the centre of mass (COM) features are controlled in AP direction when young and elderly (7 young and 7 elderly) performed sit to stand activity [27]. Subjects were asked to do various different trials, eyes open and stand up in normal paste, eyes open and stand up fast, eyes folded and stand up in normal paste and then eyes folded and stand up fast. Results concluded lower maximum peak of COM velocity in AP direction and lower COM velocity right after seat off for elderly adults. When subjects had eyes folded the maximum velocity difference increased. Centre of mass position shifted back for elderly compared to younger right at the seat off [27].

A study compared different speed to upper body stability during gait to investigate if a person is more stable during slow or fast walk activity. Eleven healthy young subjects were recruited to walk on a treadmill and 3D motion was observed in the upper body. Investigators concluded that by walking slower increases the stability. This result supports clinicians assumption, that patients and elderly walk slower to improve the balance [34].

Another study was performed to evaluate motion range in knees and hip joints in sagittal plane during stair walking. Young people were recruited for comparison, young adults, adolescents and children and divided to groups according to their stature. Vicon 460 with six infrared cameras and plug-in-gait model was used to collect kinematic data. Results concluded the body stature / step height ratio to be the main factor responsible for the dynamic motion range in the knee and hip in young people [28].

1.2.2 Functional ability with immobilised joints

A study recruited healthy volunteers to walk stairs wearing othoses on one leg to evaluate the effect on the lower body movement by immobilizing the ankle joint using different restriction strength [30]. Three trial conditions were observed, walk stair wearing a normal shoe, wearing hinged ankle foot orthoses (AFO), and finally wearing solid AFO on right leg. By using 3D motion analysis system and a force plate, kinetic and kinematic data was collected for the pelvis, hip, knee, and ankle on the right side. Results concluded shorter leg support in the right leg when walking down stairs and slower stair walk wearing AFO (for solid and hinged). Wearing a hinged AFO compared to a wearing a normal shoe did not show any significant difference in the ankle and knee motion range, powers and moments for upstairs pull up and downstairs controlled lowering in sagittal plane. The solid AFO decreased knee flexion/extension moment, ankle plantar flexion power and dorsiflexion angle compared to hinged AFO and a normal shoe during downstairs controlled lowering and upstairs pull up [30].

A previous study evaluated how a halo vest, a cervical thoracic, affected healthy male volunteers´ functional ability during gait [29]. Force plates and a Vicon motion analysis system was used to collect gait patterns and 3D data for the upper body motion or the hip, pelvis, trunk, shoulder girdle, and the head. Results concluded reduced gait speed wearing the collar. By comparing gait with and without a collar identified increased footstep duration as well as decreased step length when subjects had the collar on. Results also identify reduced hip motion, reduced movement between trunk and pelvis, and reduction between shoulder girdles and trunk movement [29].

Figure 3. Halo vest

A study using othoses which can restrict both knee and ankle (KAFO) was performed to identify if the gait kinematics improves by restricting knee flexion in stance phase [32]. This orthoses can either be locked (no knee swing or stance flexion possible), unlocked (both knee swing and stance flexion possible), or set in auto mode (knee swing possible but stance stability provided). All of these settings were observed on healthy volunteers using Ortho Trak motion analysis system. Results concluded very similar gait for the unlocked and auto mode, more similar then when locked and auto mode was compared, see table 8 below. The oxygen cost was the same for both auto mode and locked even though the auto mode provides swing flexion and the locked mode does not. Auto mode setting provided more normal gait pattern [32].

Table 8

Data (mean ± StDev) from speed-matched walking trials for nondisabled subjects walking with knee-ankle-foot orthosis that incorporated Stance-Control Orthotic Knee Joint in unlocked, locked, and auto modes.

Speed-Matched Data	Unlocked	Locked	Auto
Cadence (steps/min)	90.3 ± 7.5	89.2 ± 8.2	91.2 ± 7.8
Step Width (cm)*	14.1 ± 1.6	17.3 ± 1.8	15.3 ± 1.9
Nonorthotic-Side Step Length (cm)	62.5 ± 9.1	63.4 ± 6.1	63.1 ± 6.9
Orthotic-Side Step Length (cm)	59.4 ± 10.0	61.3 ± 7.2	59.8 ± 9.1
Orthotic-Side Support Time (gait cycle %)[¥]	62.6 ± 3.1	59.5 ± 1.9	63.0 ± 2.7
Nonorthotic-Side Support Time (gait cycle %)	65.5 ± 2.9	66.4 ± 2.2	66.7 ± 1.7

*Significant difference between unlocked and locked modes, locked and auto modes, and unlocked and auto modes.

[¥]Significant difference between unlocked and locked modes.

Table 8. Results from Zissimopoulos A.et al. 2007 [32]

Functional ability studies on healthy volunteers have concluded very interesting results. Sit to stand activity identified high knee moment right after seat off to steer the GRF slightly to posterior direction [31]. Comparison between sit to stand, stand to walk identified that sit to walk is not a stable motion [26]. When comparing young and elderly, results identified velocity difference for both groups when eyes are folded. COM position shifted back for elderly at seat off [27]. By walking more slowly increases stability during walking in the upper body [28]. Wearing othoses on one leg to restrict the ankle movement with hinged and solid AFO identified shorter leg support down stairs and slower walk wearing solid and hinged AFO compared to normal shoes

[30]. Wearing a Halo vest used to restrict the cervical spine resulted in increased footstep duration and decreased step length compared to no collar. Reduced moment between trunk and pelvis and reduction between shoulder girdles and trunk movement was identified [29]. KAFO with auto mode compared to locked and unlocked position identified similar gait for unlocked and auto mode. With the Auto mode more like normal gait [32].

1.3 Postural stability studies

Postural stability studies can be very helpful for clinicians to know if patients are in any danger falling or loosing balance after a surgery, accident, or any kind of trauma. Elderly people often experience balance difficulties. Different kinds of measuring techniques can be used to find out if a person has balance problems. It is necessary for clinicians to know about any stability problems in order to be able to address them. Also, it can be helpful for orthotists to know if any orthoses they prescribe to a patient affects the balance.

Previous stability studies have been using various measuring methods, such as measuring posturography using force plate [10], measuring unipedal stance time with and without a Halo vest to restrict neck motion and also using soft and hard surface [11], three sensitive CCD laser displacement sensors used to collect kinematic data [14], COP-based measures using a force plate [6, 8], 3D opteoelectronic camera system and a force plate used to collect kinematic and kinetic postural data [9].

1.3.1 Postural stability measures

Center of pressure based measures will be used to determine the postural stability in this study and some other are for example; mean distance (MDIST), the rms distance (RDIST), the mean velocity (MVELO), TOTEX, the mean frequency (MFREQ), 95% bivariate confidence ellipse (AREA-CE), the circle area (AREA-CC) and the sway area (AREA_SW). These are defined in more details in section 2.5.2.

1.3.2 Postural stability of the healthy population

One research study focused on difference between postural steadiness between healthy young and elderly adults [6]. The sensitivity of COP-based measures to changes in postural steadiness related to age was evaluated. Comparison of time and frequency domain measures of postural steadiness between a young and elderly adult group was performed. First, they had their eyes open and then closed. The result showed difference between subjects in the same group when the velocity of the COP was measured, both in young and elderly group. This study advances the understanding of the ways in which the postural control system is compromised with the aging process. The outcome information can be helpful in identifying elderly adults at risk of falling.

Centre of pressure displacement and the horizontal and vertical reaction forces are measured with a force plate. The force plate measures anterior-posterior and medial-lateral displacement while the body is moving to keep the centre of gravity over the base of support.

This is the first study on postural stability using force plate COP-based measures. The purpose of this study was to define and discuss COP-based measures of postural steadiness and evaluate the relative sensitivity of these measures to age related changes in postural steadiness. Measurements were used to compare postural steadiness in healthy young and healthy elderly groups, both under eyes-open and eyes-closed condition.

ANOVA measures was used to compare the results. RDIST, MDIST, CC-AREA, and CE-AREA identified difference between eyes closed and eyes open condition within the young group but did not show any difference in the elderly group. MVELO increased with age, age related change, and identified a strong difference between eyes closed and eyes open, the velocity increased when the eyes were closed compared to open. This is the only measure that identified changes that related to age in both eye conditions as well as difference between eyes open and eyes closed in both age groups.

AREA-CE, MDIST and RDIST did not identify difference in age relation in postural stability assessment but 50% Power frequency did identify difference (not significant) between the young and elderly groups as well as between eye conditions. 95% power frequency identified age related change in eye condition as well as between eyes open and eyes closed condition within the elderly group. No difference was found between eyes open and eyes closed within the young group. Hybrid measures (AREA-SW, MFREQ) identified difference between eye conditions for the older people but not for the young people.

The result is useful for clinicians and researchers to evaluate changes with age or neurologic disease, the effect of rehabilitation interventions or pharmacologic treatment, or the elderly´s risk of falling [6].

A previous study was performed to analyse quiet stance investigating strategies for balance maintenance [15]. The experimental methods used was bipolar electrodes with preamplifiers for EMG data collection, five camera Vicon system to collect kinematic data, and a force plate to collect data to determine COP. Results from all of these methods were cross-linked.

Seven male subjects were recruited within the age range 24-54, were asked to stand still with gap between their feet while holding a wooden bar, first with eyes open for 50 seconds and then with eyes closed for 50 seconds. After that they needed to stand still with feet together without a gap (Romberg stance), first with eyes open and then eyes closed. Each trial duration was 50 seconds and five trials for each condition. Normal stance with open eyes concluded more sway around the hip compared to ankle in the sagittal plane. Results suggested a dominant ankle mechanism in the sagittal plane. When looking at the frontal plane for normal stance identified that ankle and hip movement control the ML sway.

Stance with no gap between feet results identified a decreased importance of the ankle mechanism in the sagittal plane and an increased importance of hip mechanism with eyes open. Narrow stance results while looking at the coronal plane identified increased hip and ankle mechanism correlation. This is suggested by improved relationship between hip and knees in the ML motion as well as greater hip angle movement. Hip ankle and hip point correlation decreased, as well as hip angle correlation in frontal and sagittal plane appeared. This concludes AP-ML equilibrium interaction.

By comparing the eyes open and eyes closed trials identified no change in postural sway. It might have to do with increase in vestibular and/or proprioceptive senses when eyes are closed. Sensory factors are important for postural stability.

By comparing a normal stance and narrow stance, center of gravity (COG) is positioned further away from the mid ankle (further forward) when a person is standing normally. Mechanisms in the ankles control in a normal stance in the sagittal plane but during narrow stance in sagittal plane, the hip mechanism importance increases and ankle mechanism decreases in the sagittal plane. Also, both hip and ankle importance increases in frontal plane [15].

A study investigated how coordination between the joints in the hip and ankle is controlled during a quiet standing [14]. Recent studies have shown relationship between quiet standing and an inverted pendulum that rotates around the ankle joint with no significant movement around the joint in the hip. However, other studies have shown that hip joint movement is likely to have a great role in maintaining the COM above the area that is supported.

Volunteers were asked to stand still and quiet for 30 seconds, first with their eyes open and then with their eyes closed. Three CCD laser displacement sensors were used to measure angular displacement, velocity, acceleration around the joints in the hip and ankle. The result showed significant difference between the hip and ankle displacement, velocity, and acceleration (parameters for hip was greater), and thus, this confirmed that the hip joint movement cannot be disregarded during quiet standing. These results suggest that the angular movement around joints in the hip and ankle are to decrease acceleration of the COM, not to keep the COP constant [14].

A study on the connection between COP and COM during quiet standing was performed using 3D opteoelectronic camera system and a force plate [9]. Kinematic and kinetic data set was used to promote the use of a simple inverted pendulum model to be a representative for a quite standing postural control. 11 healthy volunteers were asked to stand still on a force plate with shoulder width between their legs and arms relaxed while looking straight forward for 120 seconds. 21 infrared diodes markers were placed on the whole body to collect the kinematic COM data and participants were barefoot so the force plate could collect accurate COP data.

Joint angles and segments were measured for the lower limbs, both sides, and the trunk. The result showed that segment COM root-mean-square displacement were strongly correlated with the height of the COM relative to the ankle joint and were temporarily locked to the movement of the full body COM. The angular displacement in the ankle when looking at the sagittal plane was strongly correlated to the COM movement in the sagittal plane. The researchers observed very strong connection between body COM and angular displacement in the lower limb which is a result of compensative angular displacement in the knee joint. These collected data extend and support the use of an inverted pendulum model to symbolize quiet standing postural control [9].

A study analysed how joints coordination affects the postural stability in quiet stance using the UCM approach (uncontrolled manifold), six camera Vicon system and a goniometer [25]. Volunteers were recruited to stand still or a force plate with arms chest folded with shoulder width between feet. Trial duration was 5 minutes, first with eyes open repeated three times, then with eyes closed three times. Result identified minimal affect on the center of mass (CM) and the head position when six joints were coordinated, their variance combined had minimal affect. When volunteers had their eyes closed the result showed increased joint variance which resulted in affecting the CM and head position stability. This discloses control strategy that involves harmonized variations of most of the joints to stabilize variables that are crucial to balance during quiet postural stance [25].

Studies noted in this chapter have concluded that there are different statistical measures that identify difference between eye conditions for young and elderly, as well as identifying increased COP trace length with age [6]. A study concluded that hip and ankle movement decreases acceleration of COM, not to keep COP constant [14]. Another study supported the use of inverted pendulum to symbolize quiet postural stance by observing very strong connection between body COM and angular displacement in lower limb [9]. Study on how different quiet stance affects the role of biomechanics for different joints when standing in a normal and then in a narrow stance as well as observing how closing the eyes affects the balance [15].

1.3.3 Postural stability with immobilised joints

Dr. Karlberg has done some interesting head-neck relationship studies and one on how restricting cervical motion effect´s the postural control and the voluntary eye movement. 11 healthy volunteers were recruited and had to wear a collar for 5 days or until it finally showed a velocity reduction of voluntary saccades and a slight anterior- posterior body sway drop induced by the calf muscles vibration. Their result indicated only a slight postural control affect while restricting the cervical motion [10].

Two groups of healthy women were recruited in a previous study, elderly and young, to see if a cervical collar affects postural stability [23]. Anterior-posterior (AP), lateral and total sway velocity was measured . Volunteers were asked to do three different trials, standing on a force plate in long base stance, standing with open eyes in wide base stance, and then stand with closed eyes in wide base stance. This was repeated wearing a collar. Results showed no significant difference between trials with and without wearing a collar. Compared to young women, elderly women showed more sway velocity ($p < 0.001$) in the long base stance trial both without and with a collar. Elderly showed significantly more sway velocity in AP and total in wide stance posture as well. There was no major difference in the lateral sway. Sway velocity was greater for both groups when eyes conditions (more with eyes closed) was compared.

The investigators conclusion was that the collar has no effect on the postural stability for both elderly and young women [23].

A study on a walking balance while wearing a cervical collar indicated no significant affect. Two groups of women, elderly and young, were recruited to testing. They were asked to walk on a computerized walk path, without and then with a collar. Double support time, and step width was measured [24].

An early study used a Halo vest, a cervical thoracis othorses, to see if cervical restriction affects balance by recruiting healthy volunteers to do unipedal stance on a soft and hard foam mat. They were asked to stand on a mat while doing the unipedal balance testing with and without the halo vest, with eyes open and closed for comparison. The testing conclusion was that a halo vest causes great reduction in balance, decrease in both functional reach and in stance time, bee table 9 below.

Table 9

Measurements of Unipedal Stance and Functional Reach Under Various Conditions

Condition	Measurement	Significance
Unipedal Stance (seconds)	Mean ± SD	
Halo vest on	29.1 ± 5.8	
Halo vest off	32.8 ± 6.4	$p = 0.002$
Eyes closed	18.2 ± 10.4	
Eyes open	43.7 ± 2.3	$p = 0.002$
Soft surface	26.6 ± 6.0	
Firm surface	35.3 ± 7.1	$p < 0.001$
Functional Reach (inches)		
Halo vest on	12.9 ± 1.4	
Halo vest off	15.1 ± 2.1	$p < 0.01$

Table 9. Results from Richardson JK.et al. 2000 [11]

It is likely that the balance reduction would be greater in older or injured patients and thus, increasing their risk of falling [11].

Another postural stability study investigated the effect of joint immobilization on the postural sway during quiet standing [8]. The purpose of this study was to examine the contribution of the main joints to the control of quiet upright stance. Ten healthy adults were recruited and asked to stand on a force plate, barefoot with comfortable width between their legs for 60 seconds, with and without immobilized joints.

Before the experiment they hypothesized that if the body acts like an inverted pendulum, restricting a joint should not have much effect on the COP, and on the trembling and rambling variables, but if it did have significant effect on the COP, trembling and rambling, it would mean that inverted pendulum does not explain the involved process in the quiet stance control.

The first part of the experiment was to restrict the knees, then both knees and hip, and finally knees, hip, and trunk. Subjects were asked to have their eyes open first and then closed. The following was analysed using a force plate; the root mean square (RMS) and mean speed of COP, rambling, and trembling trajectories in the anterior posterior and medial lateral directions.

Postural sway in the anterior-posterior direction only increased when trunk, hip and knees were restricted. When knees and hip, and knees, hip and trunk were immobilized, the mean speed of COP decreased when the subject swayed in medial-lateral direction. Also the RMS and the rambling, trembling displacement decreased. The conclusion is that the more the joints are free, a better stability is achieved, i.e. all joints work together to control the COM displacement. This means that a single inverted pendulum in not able to explain the process involved in the quiet standing postural control completely in the medial-lateral, anterior-posterior directions [8].

Studies in this chapter have concluded that a collar does not affect balance until after 5 days of use [10], no significant balance difference is identified between with and without a collar while standing on a force plate, as well as, a cervical collar does not affect gait balance [23, 24]. The last study concluded that a single pendulum cannot be used to explane the process involved in a quiet postural stance by restricting joints in the the lower body [8].

In current study we focus on the functional ability while wearing a cervical collar when doing various activities such as; stand up from chair, sit down, gait analysis and postural stability assessment. We observed how restricting the neck joint affects the joints in the lower body and not the range of motion in the neck like precious studies have focused on. We also looked at how restricting a joint motion in the neck affects postural stability by looking at change in centre of pressure (COP[1]). The latter part of the study has been more observed in the past using different kinds of measuring systems.

We hypothesized that restricting neck motion using a cervical collar might affect hip flexion in the sit-stand-sit manoeuvre. This might have consequential effects at the knee and ankle. We did not predict any significant differences in gait. Some measures of postural stability might decrease whilst wearing the collar, since the collar reduces motion at a joint which might help in the balance mechanism.

1.4 Research rationale

This study was performed to evaluate if restricting a cervical collar motion with a highly immobilizing cervical collar affects the functional ability in the lower body during sit stand sit and gait. Postural stability wearing a collar was also observed to see how neck joint restriction affects the balance during quiet stance for healthy volunteers. This kind of study using a collar has not been performed before using a light cervical collar, only by using heavy Halo vest cervical thoracic orthosis.

[1] COP is the vertical reaction vector location on the force plate surface where the subject stands. It can be used as a measuring tool with the intention to understand the mechanisms of postural control during quiet standing. [8]

1.5 Aims of the thesis

A range of motion studies have been performed in the past using a cervical collar and using various measuring tools but in the first part of this study we focus on how wearing a collar might affect lower limb joint movement in space while doing every day activity like; standing up and sitting down on a chair or walk. The second part of the current study is to see how wearing a cervical collar affects the postural stability. The first part has not been investigated before and thus, lack of previous studies on that subject.

The aim of this investigation was to measure the functional ability affect while wearing the Miami J Advanced cervical collar so it can give a better understanding on to how restricting movement in the neck affects the whole body function, both with respect to functional ability and postural stability.

2. Methodology

This study is divided to two parts. The first part is a functional kinematic study on the joint motion of the lower body without a collar compared to joint motion wearing a cervical collar. The second part of this study is an evaluation of the postural stability without a collar compared to wearing a collar. Ten participants were recruited for the first part and six for the latter one.

2.1. Participants

After University Ethics Committee approval a group of sixteen healthy adults was recruited within the narrow age range 22-32 since a wider age range might increase the variance associated with functional ability due to age difference. Ten volunteers, five females and five males, were recruited for the functional ability experiment and six participants (three females and three males) for the postural stability testing, see table 10 below.

Table 10

Participants parameters	Kinematic subjects		Stability subjects	
	Mean ± StDev	Range	Mean ± StDev	Range
Age	26.2 ± 2.4	24 - 31	25.5 ± 1.89	24 - 29
Weight	70.3 ± 8.6	60 - 86	70.2 ± 10.0	60 - 85
Height	171.9 ± 7.3	161 - 182	172.8 ± 8.2	165 - 189
Subjects count	5 females, 5 males		3 females, 3 males	

Table 10. Subject information table.

Exclusion criteria for this project included those with current musculo-skeletal or neuromuscular injury, or those taking prescribed medication. All volunteers signed an informed consent form to participate in this research, approved by the University of Strathclyde Ethics Committee. A risk assessment form was also filled out and approved by the University of Strathclyde. Consent form is attached in Appendix A.

2.2. Evaluation system

The Vicon Nexus 1.6.1. system (Vicon, Oxford) was used in this study to assess the effect of wearing a cervical collar on functional ability. This is a motion analysis system used to obtain 3D kinematic data. The Plug-in-gait™ marker set was used to investigate the functional ability impairment by comparing joint kinematic measurements from the machine on volunteers with and without the collar.

Volunteers were required to wear cycling shorts to prevent marker movement. Sixteen reflective markers were attached to the body at specific anatomical landmarks using double-sided adhesive tape according to the lower-body plug-in-gait™ model. Flexion and extension of certain joints where examined in sagittal plane to see how a cervical collar affects body kinematics while doing various functional activities. Non-sagittal plane movement was not examined.

The kinematic model obtained with a plug-in-gait™ is used to generate joint angles for the hip, knees and ankles. For the present study, only flexion-extension was examined for each lower limb joint. Figure 4 here below shows gait captured with a motion analysis system in sagittal plane.

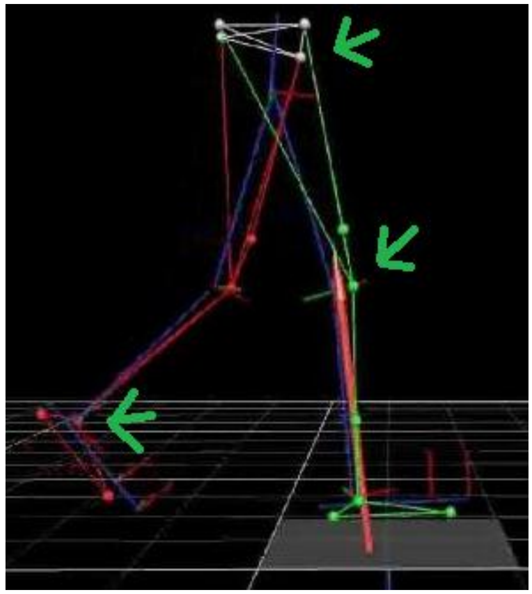


Figure 4. Joints measured

Joint angle data were calculated within the software, and post- analysed using Excel and the SPSS statistical analysis program.

In addition to the kinematic study, COP was measured from the force plate to assess postural stability. 30 seconds of force plate data was captured at 100 Hz.

Participants were required to attend the biomechanics laboratory for approximately an hour for the kinematic functional ability experiment but only 10-15 min for the postural stability testing.

2.3. Cervical collar

Cervical collars used today are very advanced and are always improving. The Miami J® Advanced, a cervical collar from Össur was the collar of choice for this study. It is a c-spine immobilizer, a semi rigid, extended-wear cervical collar, see figure 5. It is size adjustable so it fitted all of the participants recruited for this study. This collar has been achnowledged to be the best cervical spine immobilizer on the market today [7, 33].

Figure 5. Miami J Advanced cervical collar

A specialist from Össur trained the investigator in the fitting of the cervical collar.

2.4. Experimental protocol

Volunteers were asked to wear cycling shorts during the testing period to make it better to put markers on the lower body as well as no clothing should cover any markers at the risk of the cameras not being able to capture them during kinematic experiments. Markers have to be stable, not move away from the chosen locations. The collar used is manually fitted according to instructions from the manufacturer on each participant so only one collar was used throughout the whole experiment. After each test, the collar was inspected for any damages that might affect the testing on the following participant.

The number of trials for each subject was 18, described in table 11. Three trials for sit to stand movements without a collar, three stand to sit without a collar, three for sit to stand wearing a collar, and then three stand to sit wearing a collar to improve measurements reliability. Participants in the postural stability experiment were asked to perform one trial with open eyes without a collar, one trial with closed eyes without a collar, one trial with open eyes wearing a collar, and finally one trial with closed eyes wearing a collar.

Table 11

Number of trials in experiment

Trial	Gait analysis	Sit to stand	Stand to sit	Postural stability
No collar	3	3	3	2
With collar	3	3	3	2

Table 11. Functional ability assessment, number of trials

2.4.1 Gait analysis

The gait analysis was repeated three times with the collar and three times without the collar. Subjects were asked to walk normally through the capture area to see how the neck restriction affects the joint motion in the hip, knees, and ankles while walking.

2.4.2 Sit to Stand and Stand to Sit

After the gait trials, each participant was asked to sit down on a height adjustable bed, and then stand up, without the collar three times. This was repeated wearing a collar. A height adjustable bed was used in order to be able to adjust the height so that the participant´s legs would form a 90º angle, or close to that, while sitting down. Subjects were asked to keep their hands relaxed and not use them for support.

The following joints where analysed in the sagittal plane for the trials sit to stand, stand to sit trials, see Appendix B for kinematic data: Hip maximum flexion, knee maximum flexion, and finally an ankle maximum flexion was used for comparison.

Each participant took approximately one hour to complete the first two sets of the experiment, or the kinematic functional ability testing, gait and sit stand sit manoeuvres. Analysis of variance was then used to assess any differences between the experimental conditions.

2.4.3 Postural stability

In addition to the kinematic study, postural stability was assessed. Six participants were assessed[2]. A subject was asked to stand on a force plate, first without the collar, barefoot with feet touching (Romberg stance[3]) and arms relaxed for 30 seconds. Standing data was measured to assess centre of pressure movement, captured at 100Hz. Next, subjects were asked to close their eyes while standing in the same position on the force plate. This was done once without the collar with their eyes open, once without the collar and eyes closed, once with the collar and eyes open and once with the collar and eyes closed. Trial duration was 30 seconds and one trial for each condition. The purpose of the stability testing is to see how the collar affects the subject´s balance.

[2] Originally the ten participants recruited for the functional ability test also underwent postural stability measurements. However, due to a technical problem, these data were unreliable and the protocol was repeated on a further six participants.

[3] Romberg stance is when a subject stands still with feet together and arms down at the side with eyes open and then closed. Sway is observed for both conditions and compared.

The second set of trials, or the postural stability experiment, took about 10-15 min for each subject to complete, see Appendix B for COP-based measures data for all subjects. Analysis of variance was then used to assess any differences between the experimental conditions.

2.5 Data analysis

2.5.1 Functional ability measures

Kinematic data was collected using the Vicon system. By using the plug-in-gait the system calculates the angles for each joint in the lower body. By using the data given to plot the graphs, it is possible to note the maximum and minimum angles peak for the hip and ankles, but for the knee the maximum stance peak and maximum swing peak is collected. Range of motion (max-min) for the hips and ankles was also determined.

After all the peaks have been collected for each trial and for all subjects, ANOVA analysis is performed using SPSS statistics package. The statistic results are used to compare the joint motion between trials, subjects and genders.

The same is done for sit to stand and stand to sit data but this time only the maximum peak is used to compare the statistic results for all joints.

2.5.2 Postural stability measures

To evaluate the postural stability, a force plate was used. To compute the COP measures, the output from the force plate was assessed for x and y coordinates. Participants were asked to stand on a force plate, barefoot with their feet touching and hands down to the sides (Romberg stance). They were asked to stand still and look straight ahead, facing the force plates anterior direction. Trial duration was 30 seconds for each trial condition. To evaluate the COP measures, the following equations where used to calculate MDIST, RDIST, TOTEX, MVELO, AREA-CC, AREA-CE, AREA-SW and MFREQ.

a. The first four measurements gives the distance measures.

Mean distance is found by

$$MDIST = 1/N \sum RD[n]$$

where mean distance (MDIST) is the average of the resultant interval (RD) time series, which stands for the average distance from the mean COP. RD time series is the vector distance from the mean COP to each pair points in AP_0 and ML_0 time series, were AP stands for anterior-posterior, and ML stands for medial-lateral.

rms distance is found by

$$RDIST = \sqrt{1/N \sum RD[n]^2}$$

Where RDIST is the rms distance from the average COP is the RMS of the RD time series.

Total excursions is found by

$$TOTEX = \sum \sqrt{(AP[n+1] - AP[n])^2 + (ML[n+1] - ML[n])^2}$$

Where TOTEX, or the total excursions is the length of the trace of COP travelled. It is estimated by the sum of the interval between sequential points (n and n+1) on the COP path.

The mean velocity is found by

$$MVELO = \frac{TOTEX}{T}$$

Where MVELO, or the mean velocity is the speed of the centre of pressure travel.

b. The following equations were used to evaluate the COP area, or the area under pressure.

Circle area is found by

$$AREA - CC = \pi(MDIST + z_{0.5} s_{RD})^2$$

Where AREA-CC is the area of a circle with radius equal to the one sided 95% confidence limit of the RD time series. $z_{0.5}$ is the statistic at the 95% confidence level, which is 1.645, and s_{RD} is the standard deviation of the RD time series.

$$s_{RD} = \sqrt{RDIST^2 - MDIST^2}$$

To be able to calculate the confidence ellipse area (AREA-CE) we need to find the major a and minor b radii of the 95% confidence ellipse.

Major radii is found by

$$a = \sqrt{F_{0.05[2,n-2]}(s_{AP}^2 + s_{ML}^2} + D)$$

Minor radii is found by

$$b = \sqrt{F_{0.05[2,n-2]}(s_{AP}^2 + s_{ML}^2} - D)$$

Where,

$$D = \sqrt{(s_{AP}^2 + s_{ML}^2) - 4(s_{AP}^2 s_{ML}^2 - s_{APML}^2)}$$

$F_{0.05[2,n-2]}$ is the F statistic at a 95% confidence level for a bivariate distribution with n data points. s_{AP} and s_{ML} are the standard deviations of the time series in AP and ML. s_{APML} is the convariance, s_{APML}=1/N∑(AP [n]ML[n]).

After simplifying these equations above we get the equation for AREA-CE

$$AREA - CE = \pi ab = 2\pi F_{0.05[2,n-2]}\sqrt{s_{AP}^2 s_{ML}^2 - s_{APML}^2}$$

The AREA-CE equation measures the area of the 95% bivariate confidence ellipse, which is expected to enclose approximately 95% of the points on the COP path.

c. The final two equations describe the hybrid time domain with distance measures combined.

The sway area is found by

$$AREA - SW = \frac{1}{2T}\sum_{n=1}^{N-1}|AP[n+1]ML[n] - AP[n]ML[n+1]|$$

Where the sway area, or AREA-SW evaluates the enclosed area by the centre of pressure path per unit of time.

The mean frequency is found by

$$MFREQ = \frac{TOTEX}{2\pi MDIST\ T} = \frac{MVELO}{2\pi MDIST}$$

Where the mean frequency, or MFREQ gives us the rotational frequency (Hz) of the COP if it had travelled the total excursions around a circle with a radius of the mean distance.

These stability measures are the same as used in a previous study [6].

2.5.3 Statistical analysis

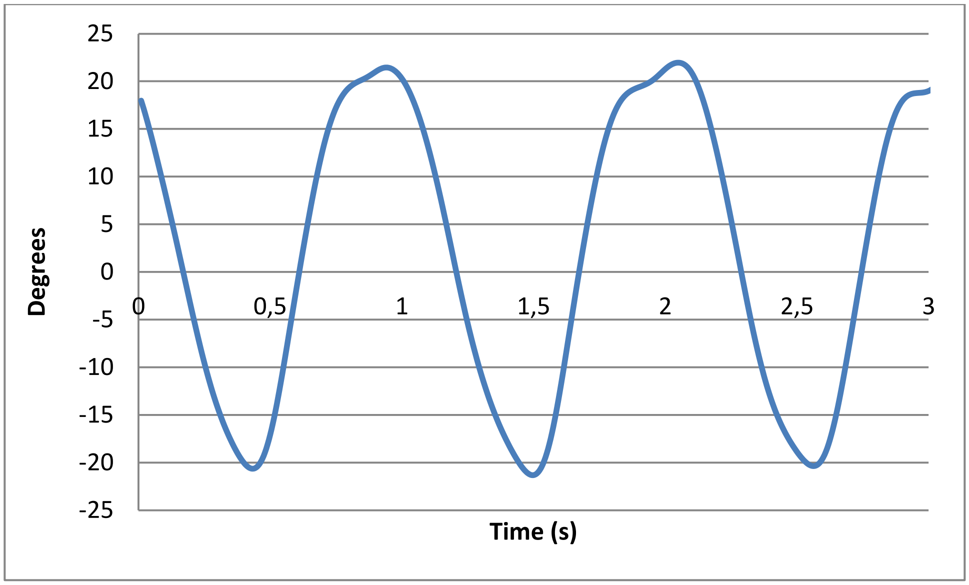
All outputs from the Vicon system were assessed and the SPSS statistical analysis program was used to conduct the statistical results. Repeated measures ANOVA analyses were performed for each dependent variable. Trial number (1-3) and collar (yes/no) were within subjects factors for the gait and sit stand sit analysis, and gender was intended as a between subjects factor. For the stability analysis, only one trial for each test was performed and then the same subject factor for collar (yes for with a collar/no for without a collar). Addition to the postural analysis was eyes (eyes open/eyes closed). Level of significance was taken at $p < 0.05$.

Number of trials for the kinematic experiment was 18 for each participant and 4 for the participants in the postural stability experiment. For the kinematic testing, subjects without a collar were compared to subjects wearing a collar. Trial and gender comparison was analysed as well. Comparison between open eyes and closed eyes was computed in the stability assessment, as well as with and without collar comparison.

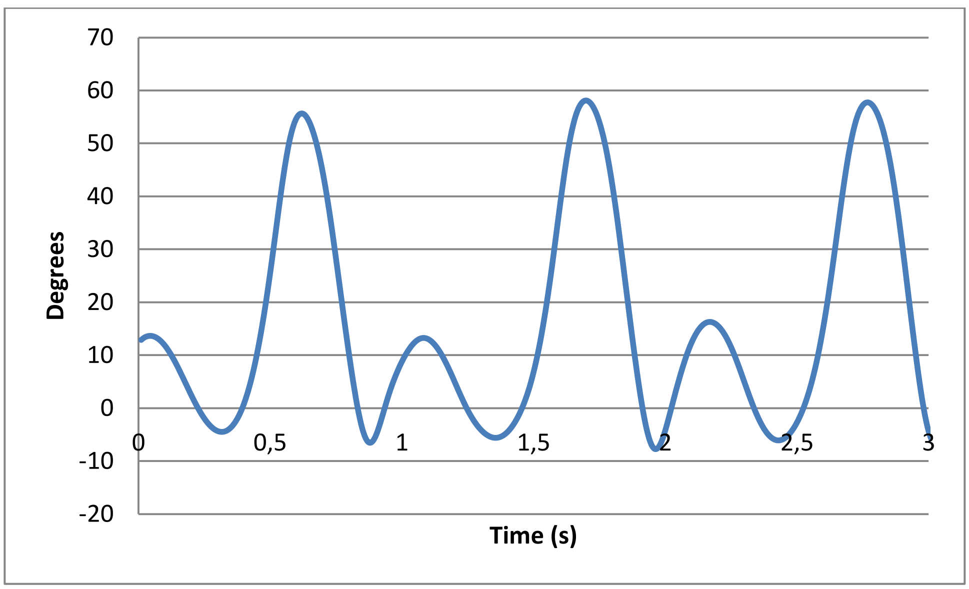
3. Result

3.1 Kinematic experiment

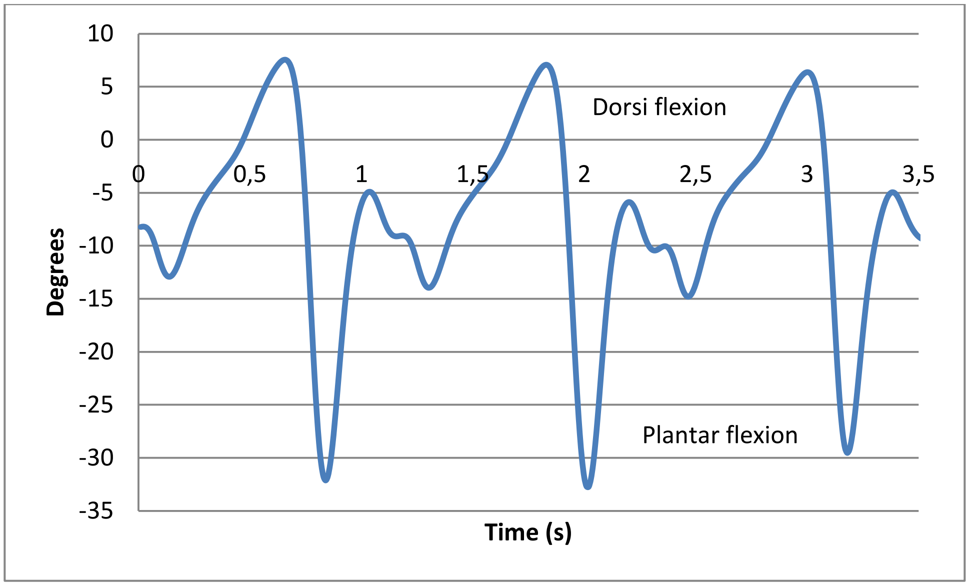
Typical joint flexion extension data was obtained for joint angle comparison between subjects for various activities, see graphs 3 to 11 here below.



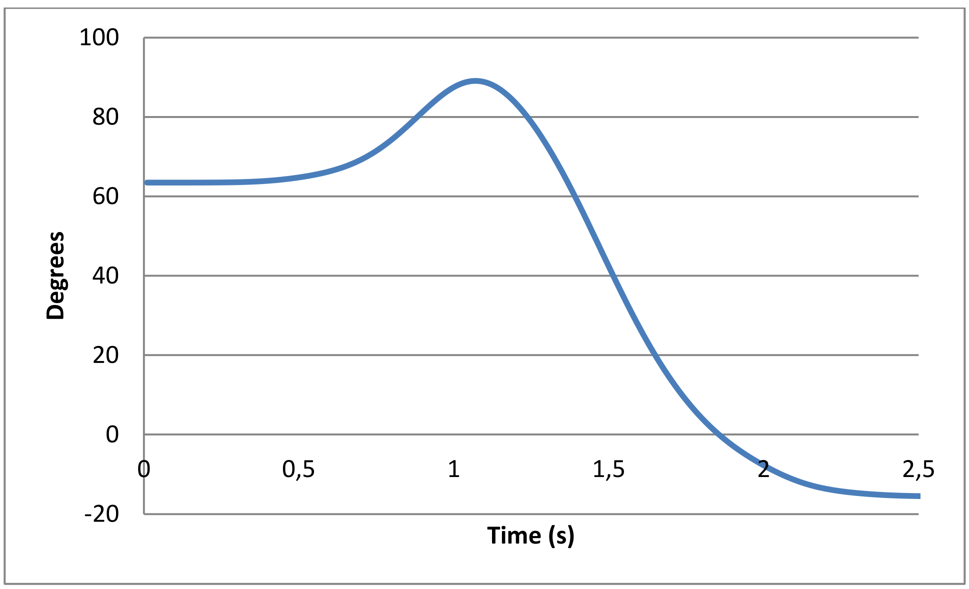
Graph 3. Typical hip flexion extension during gait



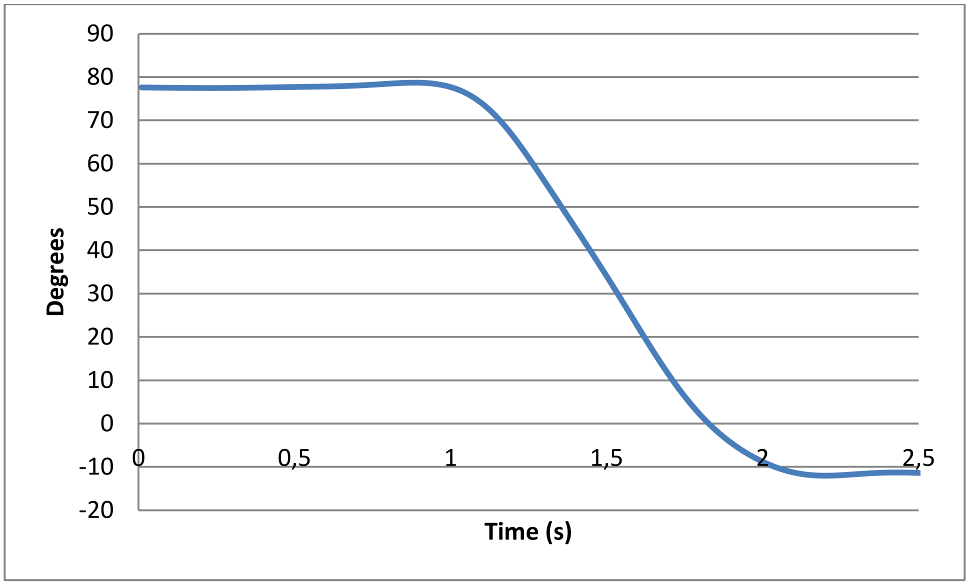
Graph 4. Typical knee flexion extension during gait



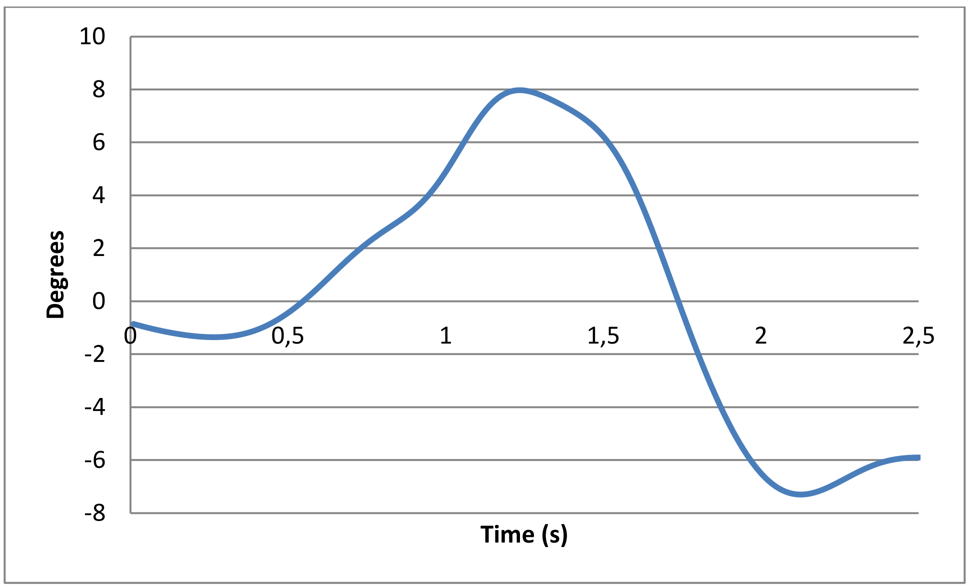
Graph 5. Typical ankle dorsal plantar flexion during gait



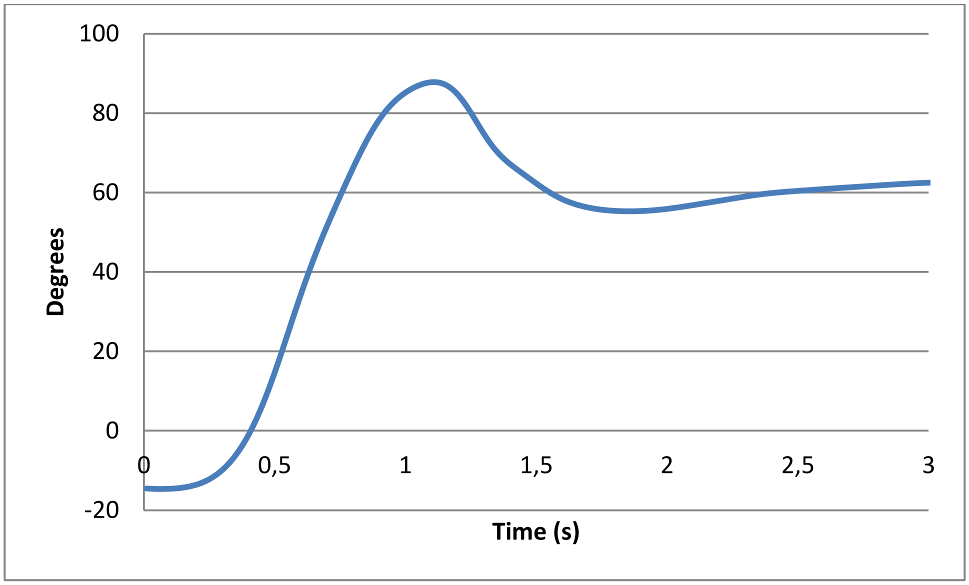
Graph 6.Typical hip flexion extension during sit to stand



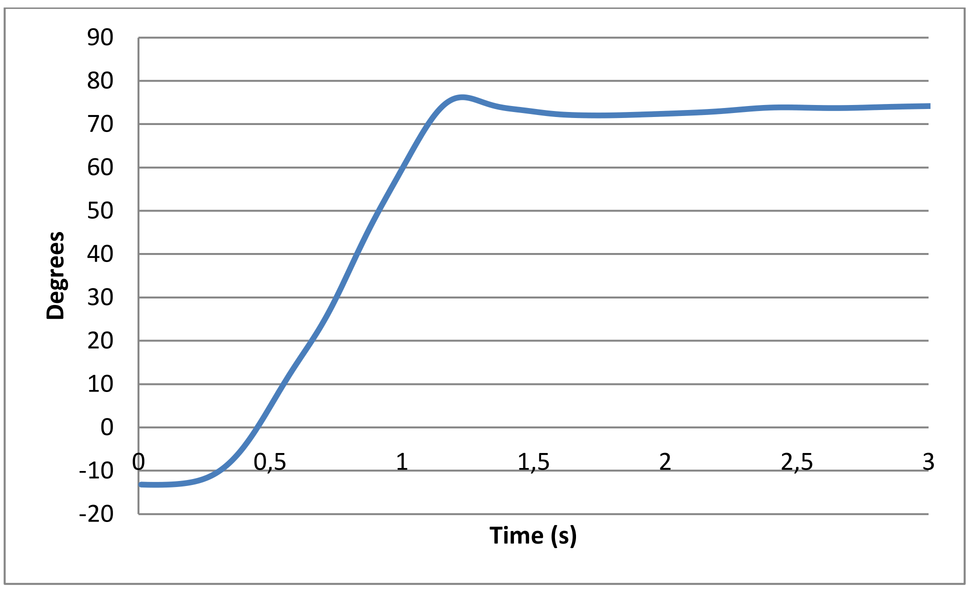
Graph 7. Typical knee flexion extension during sit to stand



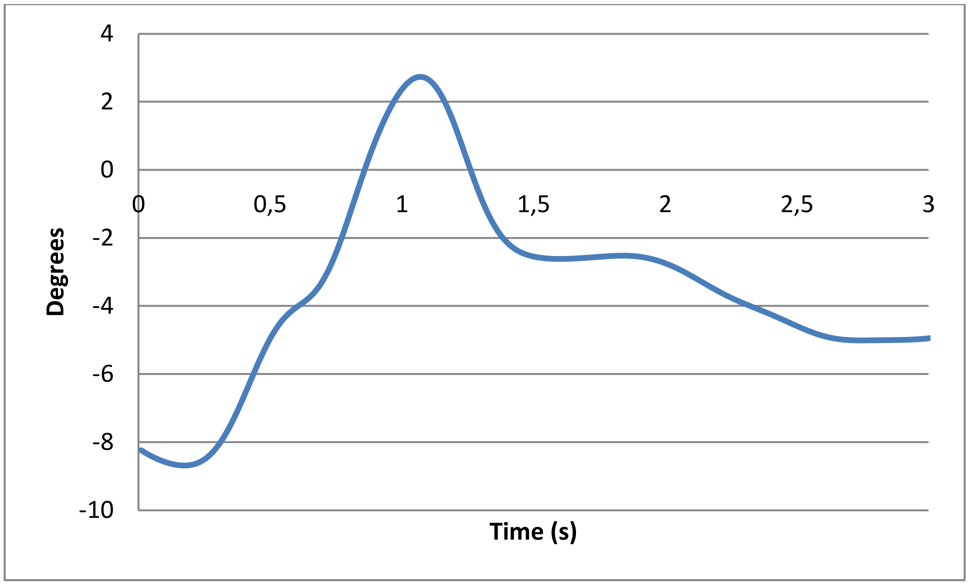
Graph 8. Typical ankle dorsal plantar flexion during sit to stand



Graph 9. Typical hip flexion extension during stand to sit



Graph 10. Typical knee flexion extension during stand to sit



Graph 11. Typical ankle dorsal plantar flexion during stand to sit

3.1.1 Gait

When comparing the joints movements in the sagittal plane, with and without wearing a collar, no significant difference for joint movements was observed except for the ankle range of motion (ROM). There was a significant effect ($p < 0.05$) of collar on ankle range of motion, with the collar reducing ankle range of motion by 1.8º (table 12 and 13a and b).

No significant differences were observed in any measure between the genders and further, there was no interaction effect between collar and gender and thus, both genders, male and female, respond similarly to wearing a collar.

The maximum hip movement and the hip ROM varies significantly between trials. The difference is less than 1º (0.720º for hip max and 0.814º for hip ROM), see tables 12 and 14 below.

Table 12				
Measures	NC vs. WC	Collar and gender	Trials	Gender
Hip max	0.876	0.325	**0.032**	0.134
Hip min	0.376	0.341	0.598	0.369
Hip ROM	0.360	0.790	**0.020**	0.203
Knee max stance	0.960	0.665	0.324	0.515
Knee max swing	0.689	0.829	0.199	0.592
Ankle max	0.241	0.742	0.206	0.203
Ankle min	0.209	0.902	0.389	0.384
Ankle ROM	**0.032**	0.961	0.764	0.950

Table 12.Significance values for the various factors were P < 0.05 is a significant difference.

Table 13a										
Trials	Hip max		Hip min		Hip ROM		Knee stance		Knee swing	
Collar	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Mean	29.369	29.235	-12.204	-11.592	41.573	40.827	11.376	11.405	54.701	54.518
St. errors	2.886	2.449	3.099	2.844	1.445	0.910	1.871	1.671	1.992	1.902

Table 13a. Mean and standard errors for hip and knee movement (deg)

Table 13b						
Trials	Ankle dorsal		Ankle plantar		Ankle ROM	
Collar	No	Yes	No	Yes	No	Yes
Mean	6.036	5.494	-22.747	-21.544	28.783	27.038
Standard errors	1.530	1.541	2.370	1.918	2.621	2.365

Table 13b. Mean and standard errors for ankle movement (deg)

Table 14						
Trials	Hip max 1	Hip max 2	Hip max 3	Hip ROM	Hip ROM 2	Hip ROM 3
Mean	28.862	29.460	29.582	40.673	41.438	41.487
Standard errors	2.675	2.611	2.659	1.148	1.097	1.221

Table 14. Mean and standard errors for hip movement (deg)

3.1.2 Sit to stand to sit

There was no significant difference in joint motion in the lower body when participants sat down and stood up, with regards to wearing a collar, see tables 15, 16 and 18 below.

No significance difference was identified when males and females were compared, see tables 15, 16, and 17 here below.

However, there was a significant difference ($p < 0.05$) between trials concerning peak hip flexion between trials, see table 15 below.

Table 15

Joints	NC vs. WC	Collar and gender	Trials	Gender
Hip	0.485	0.865	**0.023**	0.129
Knee	0.358	0.799	0.121	0.108
Ankle	0.576	0.774	0.052	0.382

Table 15. Sit to stand. P < 0.05 is a significant difference.

Table 16

Joints	NC vs. WC	Collar and gender	Trials	Gender
Hip	0.499	0.691	0.992	0.054
Knee	0.291	0.856	0.642	0.112
Ankle	0.317	0.434	0.712	0.520

Table 16. Stand to sit. P < 0.05 is a significant difference.

Table 17			
Sit to stand	Gender	Mean	Std. Errors
Hip	Female	94.143	3.598
	Male	85.539	3.598
Knee	Female	77.009	3.212
	Male	85.229	3.212
Ankle	Female	7.476	2.247
	Male	10.416	2.247
Stand to sit			
Hip	Female	92.879	3.696
	Male	81.104	3.696
Knee	Female	77.365	3.345
	Male	85.801	3.345
Ankle	Female	5.237	2.439
	Male	7.560	2.439

Table 17. Mean and standard errors between genders for hip, knee and ankle (deg)

Table 18.			
Sit to stand	Collar	Mean	Std. Errors
Hip	No	90.495	2.745
	Yes	89.187	2.647
Knee	No	80.457	2.658
	Yes	81.781	2.042
Ankle	No	8.712	1.850
	Yes	9.180	1.397
Stand to sit			
Hip	No	87.582	2.875
	Yes	86.401	2.605
Knee	No	80.901	2.613
	Yes	82.264	2.255
Ankle	No	5.745	1.807
	Yes	7.052	1.852

Table 18. Mean and standard errors between collar and no collar (deg)

3.2 Postural stability experiment

3.2.1 Force plate

Wearing a collar showed no significant effect on any postural stability measure. However, there was a trend that the length of the COP path (TOTEX), and the velocity of the COP (MVELO), decreased by wearing a collar ($p < 0.1$).

As expected, and in agreement with literature, shutting the eyes increases the length of the trace of COP travelled ($p < 0.01$), increased the speed of the COP travel ($p < 0.01$) and increased the sway area ($p = 0.01$).

Finally, there is a significant interaction between wearing a collar and shutting the eyes regarding sway area (AREA-SW). With the collar off, a large difference in sway area is seen between the eyes open and eyes closed conditions (with the eyes closed having a greater sway), but wearing a collar reduces this difference, see tables 19 and 20.

Table 19

Measures	**NC vs. WC**	**EO vs. EC**	**Collar and Eyes**
MDIST	0.953	0.847	0.514
RDIST	0.819	0.567	0.379
TOTEX	0.081	**0.002**	0.183
MVELO	0.072	**0.003**	0.312
MFREQ	0.320	0.778	0.908
AREA_CC	0.819	0.567	0.379
AREA_CE	0.871	0.175	0.486
AREA_SW	0.480	**0.010**	**0.040**

Table 19. Postural stability measures. P < 0.05 shows significant difference. NC=No collar, WC=with collar, EO=eyes open, EC=eyes closed.

Table 20

AREA_SW	Mean	Std. Errors
Eyes open	65.257	4.899
Eyes closed	96.598	9.224
EC no collar	105.375	12.676
EC with collar	87.821	8.013

Table 20. Sway area comparison.

EO=eyes open, EC=eyes closed (deg)

4. Discussion

The aim of this investigation was to measure functional ability affect while wearing Miami J cervical neck collar to get a better understanding of how restricting movement in the neck affects whole body function. This might help manufacturers to find ways to improve the functioning of the collar so that it better achieves its medical purpose while minimising unwanted functional deficits.

Previous kinematic studies have focused on how the neck motion range is restricted with a collar. Studies have proved that Miami J Advanced cervical collar restricts the motion range better than other cervical collars [33]. Because of these information we can be sure that the collar is immobilizing the neck joint well enough before proceeding to the experiments. Lack of motion restriction cannot be the reason why wearing a collar does not affect the gait and the sit stand sit trials performed in a current study more than it did.

In this study we examined the body functional ability during walking, sit to stand, and stand to sit with and without wearing a cervical collar. By comparing young and elderly volunteers has concluded different centre of mass position during seat off [27]. High knee moment is identified at this time to steer the ground reaction force backward [31] and thus, these studies show that elderly need higher knee moment to keep balance during this activity. A current study only recruited young and healthy volunteers so by recruiting elderly and compare to young would possibly identify more significant difference in functional ability wearing a collar. Another study concluded more upper body stability during slow walk [33]. Volunteers in current study performed the gait activity on their own comfortable pace so that could have affected the results.

Studies using orthoses to immobilize joints have concluded reduced functional ability during various activities. One study recruited healthy volunteers to wear two different ankle orhoses (hinged and solid AFO) and then a normal shoe for comparison on one leg. It concluded shorter leg support while walking down stairs as well as slower walk wearing a solid and hinged AFO compared to normal shoe [30]. A study using KAFO (knee ankle foot othoses) with auto lock mode identified more normal gait pattern when it is set to auto mode which allows knee swing but provides knee stance stability [32].

Wearing a halo vest cervical thoracic reduces moments between trunk and pelvis, between shoulder girdles and the trunk as well as increasing footstep duration and decreasing step length during gait [29]. This concludes by restricting neck motion reduces the motion ability in the upper body during walking.

There was a significant effect ($p < 0.05$) of collar on ankle range of motion for gait activity, with the collar reducing ankle range of motion by 1.745º. Even though there is a significant statistical difference does not mean that the collar has clinical affect, it is only about 1.8º. This is only 0.06% ankle movement decrease so that should not affect the body's functional ability during gait. This finding demonstrates the accuracy of the Vicon motion analysis system since it has identified a small significant difference with only N=10.

The maximum hip movement and the hip ROM varies significantly between trials. Participants could be getting more comfortable after each trial and thus, start to walk faster and more relaxed. The difference is less than 1º (0.720º for hip max and 0.814º for hip ROM), which is a very small difference, and hence no clinical significance.

Only the sagittal plane was observed in this study. If the coronal plane (frontal plane) would have been observed as well, It is possible that a greater significant difference in joint movements would be observed, especially in the hips between the gait trials, with and without the collar. A knock on affect from the hip should affect the joint movement in the knees and the ankles in the coronal plane. Qualitatively, participants reported about how the restriction in the neck affected their walking although almost no significant difference in our results. They felt like they were for more upright with the collar on like having broader back, less flexible, and did not feel as relaxed compared to without the collar, so they felt like the hips did not move as much to the sides during walking. This is a probable scenario, and might be proven if the coronal plane would be observed. A previous study using Halo vest to restrict the neck motion has concluded deceased step length and reduced moment between trunk and pelvis during gait [29].

Sit to stand and sit to stand experiment results did not show any significant functional difference in joint motion in the lower body with a collar on compared to with no collar. Participants were asked to sit with their feet forming 90° and hands relaxed but it was not always the case. Some of the participants were too short to reach the ground in that position and sometimes after the first trial, they sat in a little bit different position before the next trial started. To prevent that from happening, the investigator could have asked the participant to move the behind a little bit further back after each trial.

If the investigator would have asked the participants to sit further back in the seat, different results might have been obtained. It is more difficult to stand up from that position and even more difficult with a collar on, so it is assumed that it would have shown significant difference.

There is a significant difference between trials in the hip movement ($p < 0.05$). The reason could be, participants are getting more comfortable with what they are supposed to do after the first trial, as well as they might be sitting closer to the edge of the seat after the first trial like was mentioned above.

The functional ability experiment showed almost no effects on the joint movements in the lower body while using a cervical collar which is reassuring for those wearing collars. Therefore, this suggests that any functional deficit in users may be attributed to their injury, rather than the collar itself. However, by only analysing the sagittal plane, there is no way to know if the collar was affecting the joint movement laterally.

The postural stability experiments gave some interesting results. By restricting the neck movement the participants were more stable, both with eyes open and closed compared to not wearing a collar. The collar reduces the sway area difference between open and closed eyes. A possible reason for this could be that by using a collar and reducing the degrees of freedom involved in postural stability, one is making the head part of the trunk. Therefore the motion of the head and trunk about the hip joint is greater and thus angular accelerations are less for the same muscle force. Potentially when the neck is free to move, motions of the head may have same knock-on de-stabilizing effects on other joints and the COP position in general.

Results from eyes closed trials compared to with eyes open, showed significant effect on the length of the COP path (TOTEX), the velocity of the COP (MVELO) and the sway area (AREA_SW). An increase in the COP travel speed, in COP trace length as well as increased sway area when eyes are closed.
A previous postural stability study [6] identified an increase in MVELO with eyes closed compared to open. However, their results differed from ours since they found a difference between RDIST, MDIST, and AREA_CC between eye conditions within the young people group. No significant difference in AREA-SW was found between eye condition for young healthy people in the previous study [6].
The reason for this different outcomes for eye condition comparison can be because subjects in current study were standing with feet close together, no gap, but in the previous study, subjects were asked to stand in a comfortable stance. A person is more stable when they stand in a comfortable, self-chosen position.

Wearing a collar resulted in no significant effect on any postural stability measure. Nonetheless, there was a trend that the velocity of the COP (MVELO) and the COP path length (TOTEX) decreased by wearing a collar and with more participants this may reach significance. This suggests that wearing a collar has a stabilizing effect on postural stability. Although, since this is not evident in the other measures, more work is required to explain this data.
Since the results determined a significant difference between the eyes condition, increase in COP path, COP velocity and sway area when eyes closed, it indicates that the conducted test is of sufficient quality and accuracy to determine significant difference in postural stability measures, suggesting that any lack of significance regarding wearing a collar is not due to experimental errors or the low statistical power of the test, but rather due to low effect of wearing a collar on postural stability.

The interaction between shutting the eyes and wearing a collar identifies significance effect in the sway area. When eye conditions are compared when subjects are not wearing a collar, there is a great difference in sway area, but when the collar is used the sway area difference between both eye conditions reduces. Thus, this indicates again the collars stabilizing effect in postural stance along with the decrease trend in MVELO and TOTX when wearing a collar, as noted above.

Previous studies on how a collar affects the postural stability showed velocity reduction and slight AP body sway drop after a subject had been wearing a collar for 5 days [10]. The reason for that could be because the subject was asked to stand with arms chest folded which might have a stabilizing affect.

Another study [23] showed no significant difference between wearing a collar and no collar while standing on a force plate in a different stance position, all with gap between feet. They identified greater sway velocity in the group of elderly compared to younger group. The sway velocity was greater for both groups with eyes closed compared to eyes open [23]. When a gait balance wearing a collar was observed, wearing a collar did not reduce the walking balance [24].
Sway area increased with eyes shut like in the current study but they did not find a balance difference due to wearing a collar. A reason for that might be the gap between the feet, subjects are more stable that way.

Using a Halo vest to observe the postural stability has been performed which indicated a reduction in balance with the Halo vest on, both in functional reach as well as in unipedal stance. This study suggests that this collar affects the users balance and, thus it can be good for the relatives to be aware of that when the patient comes home. Patients are even more unstable compared to these healthy subjects recruited in this study [11].

This study compared to current study shows a different result. Current study found increase in stability when wearing a collar but this one found stability reduction. It might have to do with the collar weight. Halo vest is about 3,6 kg but Miami J is only about 0.2 kg. By wearing a Halo vest the height of the centre of mass may be increased which would decrease postural stability. Further, it might affect the muscle fatigue in the ankle when wearing it through the whole trial period [11]. The Miami J collar is a lot lighter and so it does not increase the height of the centre mass as much and thus, does not reduce postural stability.

Subjects in current postural study were asked to stand in a narrow stance. A previous study [15] compared narrow and normal stance results. In broad stance, the ankle mechanism was dominant in the sagittal plane but when the gap was narrowed between the feet, the hip mechanism increased while the ankle mechanism decreased. More hip swing was identified compared to ankle swing when standing in a normal stance [15].

Also, in this study, there was no significant change identified in postural sway when eyes were closed compared to open. This suggests a lack of sensitivity in their experimental protocol. Increase in vestibular and/or proprioceptive senses might have to do with this result. These sensory factors are very important for postural stability [15]. In current study the postural sway increased significantly when eyes were closed compared to open eyes. The collar decreased the sway difference between collar conditions both for eyes open and eyes closed. The collar increased stability by restricting one of the joints that keeps the body upright.

A quiet postural body stance has been modelled as a single inverted pendulum. Previous studies reached different results concerning this matter. One study restricted different lower body joints to investigate if the process involved in the postural stance can be explained with single inverted pendulum. They concluded that this was not the case, quiet stance cannot be explained with an inverted pendulum [8]. Another study supported the use of inverted pendulum to symbolize quiet postural stance by observing very strong connection between body COM and angular displacement in the lower limb [9].

A current study is against looking at the human body as a single inverted pendulum. By supporting this connection we would be saying that the only joint in the body that controls the quiet stance is the ankle, which is not correct. Current study identified increased stability while restricting a neck joint so we can roll out this pendulum relationship once and for all. According to our results, the body does not behave completely as a rigid structure above the ankles [9].

Our results suggest that immobilising the neck joint, reducing the degrees of freedom of the balance mechanism, does not have a negative effect on postural stability in the healthy population.

5. Conclusions and further work

Our study concludes that wearing a cervical collar has minimal effect on the users´ functional ability and on postural balance.

In the current study, only the sagittal plane was analysed for the functional ability experiment. This may be a factor in the conclusion. Further work is recommended to find out how the neck restriction affects motion in the coronal plane during gait and sit to stand, stand to sit activities.

The postural stability trials were taken one after another without a break, that can be an error factor because the subjects could be getting tired in the last trial and thus, might be more unstable because of that, although there was no evidence of this in the results. Also, there were only six people that took part in that part of the experiment and that is an error factor. The ANOVA statistics showed a trend that TOTEX and MVELO decreased by wearing a collar and so, more people might have shown significant difference in the TOTEX and MVELO in the collar comparison test. It has been suggested that an increase in inertia about the hip joint may explain this phenomenon.

A previous study identified a difference between sit to stand and sit to walk and computed that sit to walk was an unstable motion [26]. Further research using a cervical collar should conclude sit to walk in the functional ability assessment to see if wearing a collar affects the balance and thus, affect the ability to do the activity as well as without wearing a collar.

Further studies should also take into account the gait velocity and trip hazards. Volunteers should be asked to walk at a similar pace during gait activity because slow gait can have a stabilizing affect [33]. The collar may also prevent the user looking down, and thus the effect of the collar on tripping should be investigated.

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Figures

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Figure 3. Halo vest. *Spinal Cord Injury Zone*. Available: http://www.spinalcordinjuryzone.com/info/9319/halo-ring-crowns-or-vest. Last accessed 14th August 2011.

Figure 4. Sagittal gait. *Orthopaedic Biomechanics Laboratories*. Available: http://www.obl.msu.edu/gait.htm. Last accessed 14th August 2011.

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Appendix A

Consent Form

Bioengineering Unit

Biomechanical Evaluation using Miami J Advanced cervical collar

- I confirm that I have read and understood the information sheet for the above project and the researcher has answered any queries to my satisfaction.
- I understand that my participation is voluntary and that I am free to withdraw from the project at any time, without having to give a reason and without any consequences.
- I understand that I can withdraw my data from the study at any time.
- I understand that any information recorded in the investigation will remain confidential and no information that identifies me will be made publicly available.
- I consent to being a participant in the project

I (PRINT NAME)	Hereby agree to take part in the above project
Signature of Participant:	Date

Appendix B

Gait results

GAIT no collar	Pk hip max 1	Pk hip max 2	Pk hip max 3	Pk hip min1	Pk hip min 2	Pk hip min 3	Hip ROM 1	Hip ROM 2	Hip ROM 3
Subj. 1	36,194	36,652	37,195	-5,589	-6,800	-5,613	41,782	43,452	42,808
Subj. 2	18,415	19,033	18,843	-25,052	-24,250	-24,930	43,466	43,283	43,773
Subj. 3	36,689	35,081	36,975	-15,222	-17,310	-15,162	51,911	52,391	52,136
Subj. 4	43,063	44,605	46,184	4,566	3,352	4,493	38,497	41,253	41,691
Subj. 5	33,981	34,601	35,584	-1,906	-3,061	-3,404	35,887	37,662	38,988
Subj. 6	22,426	21,075	23,727	-15,300	-16,399	-15,618	37,726	37,474	39,346
Subj. 7	40,409	39,698	38,273	-1,236	-1,530	-1,918	41,645	41,228	40,191
Subj. 8	15,037	18,824	15,120	-18,621	-18,888	-18,054	33,658	37,712	33,173
Subj. 9	21,902	22,840	26,078	-20,832	-19,104	-20,102	42,734	41,944	46,181
Subj. 10	20,294	21,918	20,339	-21,060	-20,341	-21,236	41,353	42,259	41,575

GAIT collar	Pk hip max 1	Pk hip max 2	Pk hip max 3	Pk hip min1	Pk hip min 2	Pk hip min 3	Hip ROM 1	Hip ROM 2	Hip ROM 3
Subj. 1	33,400	35,176	34,541	-4,634	-4,659	-5,632	38,034	39,835	40,173
Subj. 2	19,582	21,570	21,050	-23,516	-23,538	-22,736	43,098	45,108	43,786
Subj. 3	32,422	32,890	33,634	-14,230	-14,680	-14,856	46,652	47,570	48,490
Subj. 4	42,791	42,713	43,452	3,461	3,543	1,506	39,330	39,170	41,946
Subj. 5	35,143	35,104	34,573	-6,285	-5,495	-4,820	41,428	40,599	39,392
Subj. 6	22,547	23,631	21,347	-17,276	-16,863	-16,644	39,823	40,493	37,991
Subj. 7	37,521	39,091	38,402	-0,716	-0,947	-0,801	38,237	40,038	39,202
Subj. 8	23,511	21,244	22,366	-13,726	-13,511	-13,919	37,237	34,755	36,285
Subj. 9	23,385	24,256	23,695	-18,628	-18,065	-18,472	42,013	42,321	42,167
Subj. 10	18,534	19,207	20,271	-20,416	-21,017	-20,180	38,950	40,224	40,451

GAIT no collar	Pk knee stance 1	Pk knee stance 2	Pk knee stance 3	Pk knee swing 1	Pk knee swing 2	Pk knee swing 3
Subj. 1	14,412	14,450	14,962	55,732	55,821	58,709
Subj. 2	2,633	2,599	1,984	41,308	42,508	40,568
Subj. 3	16,233	14,823	14,272	60,219	60,382	58,638
Subj. 4	8,165	6,783	10,394	51,447	52,504	52,326
Subj. 5	10,619	9,958	8,556	57,313	59,453	58,134
Subj. 6	6,480	6,506	5,141	44,981	50,138	51,261
Subj. 7	19,159	18,502	17,403	61,781	62,197	62,705
Subj. 8	3,237	8,637	4,471	52,047	59,553	51,673
Subj. 9	16,259	19,838	21,005	56,042	55,175	54,119
Subj. 10	12,214	16,284	15,286	57,105	57,516	59,672

GAIT collar	Pk knee stance 1	Pk knee stance 2	Pk knee stance 3	Pk knee swing 1	Pk knee swing 2	Pk knee swing 3
Subj. 1	11,990	12,223	11,798	55,679	53,395	54,412
Subj. 2	4,097	3,679	4,372	42,018	41,614	41,147
Subj. 3	14,391	14,659	17,256	55,710	61,227	60,255
Subj. 4	6,685	8,528	10,545	52,231	54,736	54,305
Subj. 5	9,767	12,222	12,891	57,104	58,014	58,985
Subj. 6	6,798	3,447	4,120	50,234	49,254	48,316
Subj. 7	18,716	17,403	15,963	62,594	61,668	63,873
Subj. 8	5,073	10,133	8,986	60,586	51,526	55,983
Subj. 9	19,465	20,465	18,244	52,512	53,034	55,717
Subj. 10	12,002	13,809	12,420	56,103	56,031	57,264

GAIT no collar	Pk ankle dorsi 1	Pk ankle dorsi 2	Pk ankle dorsi 3	Pk ankle plantar 1	Pk ankle plantar 2	Pk ankle plantar 3	Ankle ROM 1	Ankle ROM 2	Ankle ROM 3
Subj. 1	3,928	1,890	1,589	-18,247	-20,119	-20,901	22,175	22,009	22,490
Subj. 2	1,794	2,897	3,539	-25,857	-23,874	-23,028	27,650	26,771	26,567
Subj. 3	4,210	3,406	3,431	-30,579	-30,584	-24,809	34,789	33,990	28,240
Subj. 4	-1,367	-2,504	-1,729	-24,552	-25,947	-26,059	23,184	23,443	24,330
Subj. 5	12,695	12,753	11,313	-24,064	-24,171	-28,445	36,759	36,923	39,758
Subj. 6	9,428	9,182	11,372	-12,821	-13,006	-14,284	22,249	22,188	25,655
Subj. 7	4,901	7,006	5,518	-30,547	-32,687	-30,247	35,447	39,693	35,765
Subj. 8	10,183	11,928	11,985	-7,491	-9,989	-5,712	17,675	21,917	17,697
Subj. 9	12,283	13,371	11,485	-34,040	-27,338	-26,604	46,323	40,709	38,088
Subj. 10	2,928	1,181	0,492	-23,408	-22,244	-20,766	26,335	23,425	21,258

GAIT collar	Pk ankle dorsi 1	Pk ankle dorsi 2	Pk ankle dorsi 3	Pk ankle plantar 1	Pk ankle plantar 2	Pk ankle plantar 3	Ankle ROM 1	Ankle ROM 2	Ankle ROM 3
Subj. 1	2,874	2,078	2,644	-18,929	-15,076	-17,575	21,803	17,154	20,219
Subj. 2	0,326	2,139	2,589	-23,833	-25,250	-27,045	24,159	27,389	29,634
Subj. 3	2,804	2,638	3,321	-26,285	-24,117	-23,791	29,088	26,755	27,112
Subj. 4	-2,843	-2,709	-3,214	-23,339	-25,175	-27,361	20,495	22,466	24,147
Subj. 5	12,035	13,814	13,401	-24,004	-26,885	-22,837	36,040	40,699	36,238
Subj. 6	8,615	8,326	8,918	-13,488	-13,703	-14,748	22,103	22,029	23,666
Subj. 7	8,022	6,635	8,365	-26,257	-22,153	-25,221	34,279	28,788	33,587
Subj. 8	10,166	9,160	12,145	-11,114	-10,171	-8,680	21,279	19,331	20,825
Subj. 9	5,618	10,456	12,491	-35,876	-28,154	-24,167	41,494	38,610	36,658
Subj. 10	0,485	1,146	2,372	-20,609	-21,309	-19,164	21,095	22,455	21,535

Sit stand sit results

SitStand	Hip 1	Knee 1	Ankle 1	Hip collar 1	Knee collar 1	Ankle collar 1	Hip 2	Knee 2	Ankle 2	Hip collar 2	Knee collar 2
Subj. 1	108,792	68,1676	16,5068	97,7405	74,3437	12,7645	107,35	71,4628	19,0431	94,6319	81,4703
Subj. 2	90,406	76,5606	7,34239	92,2338	75,8637	8,20771	89,0695	78,6867	7,97022	91,48	76,6363
Subj. 3	79,149	71,6234	-1,38019	83,399	68,7738	-0,105979	78,373	74,6622	1,88679	80,5537	70,8332
Subj. 4	96,33621	93,08228	9,222179	99,898987	90,718781	7,361642	97,42509	92,9007	9,18172	98,394203	92,207901
Subj. 5	97,87237	68,65616	2,454881	103,379089	73,318428	4,925085	98,47513	67,0274	3,391791	100,49617	71,463127
Subj. 6	81,59009	88,23671	15,94105	87,868149	84,182663	12,336426	85,99339	87,189	13,41972	86,302086	83,35244
Subj. 7	95,15852	89,39174	5,747203	97,7949	85,3802	8,10438	92,48705	92,3577	9,218054	96,5006	86,7789
Subj. 8	75,8065	75,9781	12,5701	75,7792	83,8326	12,4598	73,6745	78,152	9,97124	75,076	81,7172
Subj. 9	88,0078	80,3221	3,18839	79,9496	80,4328	6,83745	87,2158	84,035	8,67923	76,9815	85,1029
Subj. 10	97,37638	86,05222	11,76935	92,176025	86,792191	13,051758	90,29326	91,11896	15,20531	85,12648	93,97052

StandSit	Hip 1	Knee 1	Ankle 1	Hip collar 1	Knee collar 1	Ankle collar 1	Hip 2	Knee 2	Ankle 2	Hip collar 2	Knee collar 2
Subj. 1	105,011	71,6652	10,3831	90,4902	75,228	12,8899	103,804	73,1324	12,7315	95,4716	79,4124
Subj. 2	88,033	79,3101	5,74967	88,8269	79,8124	6,53663	87,8021	76,2116	2,73097	88,2821	79,6682
Subj. 3	74,8141	75,4031	-0,11993	80,5992	72,6643	-1,14156	77,3381	78,2229	4,30494	80,8156	71,2723
Subj. 4	96,20194	93,56142	6,834045	95,614876	91,983597	6,861646	92,95173	93,42155	7,217122	98,029243	90,895325
Subj. 5	110,7565	67,69228	-0,92355	102,541183	71,856087	1,306193	98,11787	66,38351	-1,20122	108,602997	69,742035
Subj. 6	81,05234	86,5391	5,941482	88,733627	83,57019	9,12844	83,3161	89,31268	10,94296	86,492058	84,368271
Subj. 7	88,83683	91,56872	5,271324	91,5927	86,217	0,253767	90,79438	86,85388	0,585873	92,8664	86,6548
Subj. 8	70,6792	79,1717	10,4834	74,2109	82,2144	9,9485	73,0695	77,0939	7,65689	75,5292	83,0759
Subj. 9	77,5512	84,0671	4,20901	72,4124	84,5328	9,2705	82,9131	76,6066	-6,77984	71,0692	85,6292
Subj. 10	84,12704	90,24033	11,41724	77,763062	92,348526	12,851955	74,71483	91,65404	11,34206	79,04158	93,841537

SitStand	Ankle collar 2	Hip 3	Knee 3	Ankle 3	Hip collar 3	Knee collar 3	Ankle collar 3
Subj. 1	16,0087	103,806	73,1682	18,5489	95,763	80,3814	15,6296
Subj. 2	9,19729	91,4589	74,5895	3,99136	88,1932	78,9119	7,31404
Subj. 3	3,68799	84,3677	72,1184	-0,88076	82,3754	72,2394	2,7492
Subj. 4	9,671608	96,04137	93,57822	9,562597	97,734169	91,18119	7,867691
Subj. 5	4,264455	100,6784	66,23704	3,581547	98,405243	69,416252	4,320536
Subj. 6	16,997128	82,02634	87,64729	15,69331	87,141518	84,449364	10,335661
Subj. 7	3,27642	94,35427	87,78217	5,462948	96,0894	87,5338	3,58357
Subj. 8	9,13795	76,3334	76,4918	8,85814	72,3219	83,21	11,7311
Subj. 9	11,5677	87,7265	72,9718	1,1142	73,3381	84,1011	8,98609
Subj. 10	17,423365	87,20799	93,46207	14,08645	88,486855	94,84491	15,718657

StandSit	Ankle collar 2	Hip 3	Knee 3	Ankle 3	Hip collar 3	Knee collar 3	Ankle collar 3
Subj. 1	17,1088	104,745	74,4519	16,74	89,1412	79,48	16,2234
Subj. 2	5,66756	88,4541	78,2085	8,27073	88,2821	79,6682	5,66756
Subj. 3	-0,812685	81,0851	66,4451	-0,79573	81,9032	66,7023	-2,67614
Subj. 4	7,484269	98,99734	91,66101	7,863103	93,096359	92,446182	7,512208
Subj. 5	-0,731854	99,09975	66,17688	-3,4628	97,440399	68,134766	-1,126748
Subj. 6	9,925274	91,43632	86,56191	12,07543	88,35878	82,404251	12,001137
Subj. 7	0,523956	90,5163	88,91216	2,423775	89,778091	91,713112	2,946079
Subj. 8	8,47652	74,5893	79,4341	9,29153	74,4241	81,0725	5,88791
Subj. 9	10,8334	77,7201	73,4368	-1,9569	73,0736	85,6672	8,62369
Subj. 10	13,636377	78,93615	93,63991	13,13677	77,523956	95,626732	16,448875

COP results for postural stability

	MDIST				RDIST			
	No collar		With collar		No collar		With collar	
	Eyes open	Eyes closed	Eyes open	Eyes closed	Eyes open	Eyes closed	Eyes open	Eyes closed
Subj. 1	80,42266829	77,28012567	62,59382126	61,29236576	31365,70399	28216,0828	18037,51801	17470,09246
Subj. 2	53,8844413	57,52925238	56,07661859	54,96796819	13022,77942	13304,97869	13625,97564	13260,35025
Subj. 3	63,97896799	34,92792633	47,70333658	54,23764335	19478,65516	9168,127889	14052,18748	15581,19568
Subj. 4	55,45204749	57,146762	62,44142983	54,62603006	17191,18698	18097,82	19540,12104	17158,71256
Subj. 5	8,581388561	15,80646609	16,1646448	32,37763914	709,9985093	2922,121468	3612,256228	8644,296057
Subj. 6	61,98798906	63,82195494	66,65045854	64,52455545	18293,23021	18169,04001	21474,20599	20575,55237

	TOTEX				MVELO			
	No collar		With collar		No collar		With collar	
	Eyes open	Eyes closed	Eyes open	Eyes closed	Eyes open	Eyes closed	Eyes open	Eyes closed
Subj. 1	1066,205	1126,229	963,4984	1007,629	42,15636	44,28162	37,85848	39,33491
Subj. 2	1006,364	1441,718	1029,149	1124,097	39,46524	56,59343	40,43807	43,89574
Subj. 3	1069,365	1365,873	1085,068	1269,758	41,9085	49,35404	40,92024	48,52579
Subj. 4	1099,609	1294,127	1096,863	1264,779	41,99654	49,61509	42,74881	48,02958
Subj. 5	1392,831	1685,004	1138,317	1411,514	46,72623	57,57415	39,32011	50,86536
Subj. 6	948,4786	1144,135	964,1599	1171,911	37,07408	44,3034	37,6013	45,33505

	MFREQ				AREA-CC			
	No collar		With collar		No collar		With collar	
	Eyes open	Eyes closed	Eyes open	Eyes closed	Eyes open	Eyes closed	Eyes open	Eyes closed
Subj. 1	0,083427	0,091196	0,096261	0,102139	162347,6	146060,7	93412,53	90476,04
Subj. 2	0,116566	0,156566	0,11477	0,127096	67469,39	68939,16	70593,52	68700,53
Subj. 3	0,104252	0,22489	0,136524	0,142394	100864,6	47489,54	72770,03	80692,28
Subj. 4	0,120536	0,138177	0,108961	0,139936	89016,42	93707,17	101177,4	88846,02
Subj. 5	0,866609	0,579713	0,387141	0,250033	3695,907	15150,73	18718,45	44774,43
Subj. 6	0,095188	0,110481	0,089788	0,111822	94732,15	94096,07	111185,8	106535

	AREA-CE				AREA-SW			
	No collar		With collar		No collar		With collar	
	Eyes open	Eyes closed	Eyes open	Eyes closed	Eyes open	Eyes closed	Eyes open	Eyes closed
Subj. 1	2,66E+09	2,3E+09	1,45E+09	1,36E+09	35,91485	75,63915	61,20637	90,26507
Subj. 2	7,74E+08	8,07E+08	8,55E+08	8,09E+08	86,95395	133,4735	78,22858	124,3891
Subj. 3	1,62E+09	3,65E+08	8,55E+08	1,07E+09	55,57546	96,62929	56,23055	75,79021
Subj. 4	1,26E+09	1,33E+09	1,62E+09	1,21E+09	62,00134	65,9792	82,02717	68,43448
Subj. 5	2258082	36392672	55522555	3,05E+08	83,55567	142,0862	52,26403	88,1195
Subj. 6	1,34E+09	1,32E+09	1,97E+09	1,8E+09	55,3688	118,4445	73,75576	79,92685