Perceptuo-motor calibration and the perception of affordances following rapid growth in adolescence

by

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Declaration:

I declare that this thesis has been composed by myself and that the work in it is my own.

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Abstract:

Adolescence is usually considered to be a time of transition from child to adult. However, studies of perceptuo-motor control have tended to focus on infants and young children or on adults, despite indications that the actions of adolescent children are poorly coordinated. This thesis examines the adolescent growth spurt and resulting recalibration of perceptuo-motor control with respect to the coordination of movement.

The first four experiments compared the performance of boys aged 12 and 13 (the age when a growth spurt is most likely to be in progress) with older (aged 14 and 15) and younger (aged 10 and 11) boys on tasks where their knowledge of their ability to perform certain actions was observed. These tasks examined actions ranging from placing objects on surfaces in front of them, reaching up to place objects on high shelves, stepping across gaps and walking along balance beams. In agreement with previous research, the younger children tended to overestimate their ability more than the older children. However, overall the poorest match between predictions and actual actions was observed in the 12 and 13 year old boys. In particular, they appeared to have a problem identifying the critical point beyond which they could no longer maintain balance during an action. This was linked to complex changes which take place in conjunction with height increases at adolescence: moments of inertia of body segments change and this must be taken into account when planning actions.

The last three experiments examined the relationship between growth and performance on forward and upward reach as well as on a task where children used long sticks to increase their forward reach. In this case, the performance of boys aged 12 and 13 who had grown substantially over the previous six months differed substantially from that of boys of the same age who had grown only a small amount. Again, differences were most notable when it was necessary to identify the critical point beyond which balance could not be maintained: this was particularly apparent when reaching with long sticks. The High Growth boys greatly overestimated their ability in comparison to the Low Growth boys.

The results of the thesis highlight the perceptuo-motor changes which accompany rapid growth and demonstrate that adult patterns of movement are unlikely to be in place until the child has learned to take account of changes in height, limb length and the moments of inertia of their body and limb segments. Until this has happened, it is likely that the adolescent will occasionally perform poorly planned and coordinated movements, especially in unfamiliar situations.

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Chapter One

1. Introduction.

As they approach the end of their second decade of life, most humans finally complete a process that began with conception: they attain adult height and stature. However the growth process which leads to adult stature is by no means linear; humans experience a number of periods of accelerated growth. The first is before birth. The second is in the first year of life, during which the infant can increase in length by 50% (Johnston, 1986). The final period of accelerated growth takes place around the age of 10 for girls and 12 for boys and is known as the adolescent growth spurt (Marshall & Tanner, 1986).

Outside of these periods of accelerated growth, children's rate of growth is fairly constant, at an average rate of 5cm/year (Marshall & Tanner, 1986). During this time, children constantly test and develop their movement abilities by attempting to match them to increasingly difficult and complex situations. It must be a necessity at this stage for a child to test the limits of their abilities by overestimating what they can do. Without this, the growing child would rarely attempt anything new or different - they would never learn to walk along increasingly narrow walls, jump over increasingly wide spaces and they would never jump over higher and higher obstacles. In fact, this overestimation has been observed experimentally (Plumert, 1995, Plumert & Schwebel, 1997).

However, at around age 12 or 13 (for boys) and 10 or 11 (for girls) the rate of growth changes. Growth rate or velocity is defined as number of centimetres per year and as such, the velocity of growth can vary. As mentioned above, growth velocity is fairly constant between one year of age and adolescence. At this point, growth velocity accelerates. During a single year in adolescence, a peak height velocity (PHV) is reached, where the rate of growth increases rapidly and then immediately begins to drop towards zero. During the year of PHV, the mean increase in overall height for adolescent boys is 10.3 cm (sd 1.54), which is more than double the previous average rate of yearly growth (Marshall & Tanner, 1986).

The process of testing abilities against environmental properties must continue, but the rate of change of potential ability (as indicated by changes in height, limb length, muscle mass and strength) increases. At this point, it must be more difficult for the child to match planned movements to particular environmental circumstances. A process of recalibration of the relationship between their physical characteristics and properties of their environment must take place and must thereafter be kept in tune: in other words, a system recalibration must take place and it is likely that this recalibration would be on a larger scale than previously.

This suggests that children at this stage of development would be less able to match their abilities to given environmental constraints, since at some point the child's ability will outstrip their ***knowledge*** of their ability. Any rapid change in an established pattern may result in a period of instability before the system restabilises in a new mode (Clark, 1986) and it is often commented upon that adolescent children are awkward and clumsy for a while (Dworetzky, 1995) but this is usually attributed to their feelings of awkwardness about a rapidly changing body. However, any consideration of the morphological changes which children undergo at this stage of development indicates that this topic is worthy of more rigorous investigation.

The result of the perceptuo-motor response to this kind of change in system parameters may ultimately result in a move towards more accurate assessments of ability. The literature indicates that there are a number of typical responses to tasks when judgement of ability are required. Adults are quite accurate in their assessment of what they can do (Carello, Grosofsky, Reichel, Solomon & Turvey, 1989). However, it has also been noted that when unusual constraints are placed on the possible actions in a given situation, adults tend to overestimate their abilities more (Carello et al., 1989, Rochat & Wraga, 1997). Adults can also be induced to underestimate their ability to perform certain actions by changing key body dimensions (for example, they do not immediately recognize their new sitting height when walking on 10cm blocks (Mark, Balliett, Craver, Douglas & Fox, 1990). There is also literature that allows a comparison of the performance of children on similar tasks. No study has shown children underestimating their abilities - however no study has taken the same approach as Mark et al. (1990). Studies typically show that children are rarely accurate about their ability and that they overestimate much more than adults (Plumert, 1995, Plumert & Schwebel, 1997, McKenzie & Forbes, 1992). This is usually taken as indication that children are motivated to attempt movements at the limit of their current ability and beyond. However, these studies have examined children up to the age where the adolescent growth spurt usually occurs, but no study has examined the performance of children at this particular age. When growth stops, it is likely that the prevention of mishaps or injury becomes more important than testing a developing system.

The aim of this thesis is to examine how adolescent children cope with the changes associated with rapid growth and investigate in what ways their actions are affected both by the change and by their response to it. It is intended to investigate this topic primarily by looking at the way they use vision to plan and guide movements and to tune their perception/action systems. The intended approach to this issue looks at the unique relationship between each actor and the environment within which they act, in terms of actions that the environment affords to the individual (Gibson, 1979). In examining the affordances detected by rapidly growing adolescents, it is also intended to investigate how affordances change as the individual develops and how each individual responds to changes in affordances.

In order to create a more detailed picture of the background to this research, a number of relevant but interlinked topics will be examined below. Firstly, human growth during adolescence will be examined, followed by the consequences of this physical change in terms of the biomechanics of movement. The importance of Gibson's theory of affordances when studying physical change will be discussed, along with other theories of motor development in children. Finally, the experimental approach that this thesis takes to the investigation of the topic will be outlined in the light of the foregoing topics.

2. *Adolescent Growth*

2.1 Changes in Height

Children's rate of growth proceeds at a relatively constant annual rate from one year of age to about age ten in girls and age twelve in boys. On average, children add to their height at a rate of 5cm/year up to this time. At around age ten in girls and age twelve in boys, the rate of growth increases: in boys, it is often more than double the previous annual rate of growth: a mean value of 10.3 cm/year with a standard deviation of 1.54 cm/year has been observed (Marshall & Tanner, 1986).

Girls also experience accelerated growth about two years before boys. The increase in girls' height during this period is in the order of 9cm with a standard deviation of 1.0cm (Marshall & Tanner, 1986) but other studies have found it to be as low as 7.1cm with a standard deviation of 1.0cm (Zacharias & Rand, 1983). The different pattern of growth in boys and girls explains the differences in adult height between males and females: boys have an additional two years growing at 5cm/year before their growth spurt and when they experience it, the adolescent growth spurt involves a greater change in height over the year of peak height velocity.

There is an important implication of the smaller growth spurt in girls. Any study, such as the present study, which hopes to study the effects of the adolescent growth spurt, must be able to identify changes in height and limb length in the children who take part. Any difficulty in identifying height changes in the group studied would make it difficult to link changes in action planning to the height (and associated changes). For this reason, the present study examined the adolescent growth spurt in boys only, although awkwardness and poorly co-ordinated movement at this age are generally observed in both boys and girls.

The duration of the adolescent growth spurt is short. The point at which acceleration in the rate of growth is detected to the point at which it has returned to the previous rate of growth are separated by only 12 months. Measuring growth more frequently than six-monthly introduces many errors when attempting to compute growth rate (i.e. difference between height at each measurement): measurement error on each occasion, seasonal variations in growth and non-linear growth rate. Most longitudinal studies of growth have used a six-monthly measurement design, but some studies on adolescent growth have used three monthly measurements (Healy, 1986).

2.2 Changes in other body dimensions

The increase in height associated with the adolescent growth spurt is due to changes in the dimensions of individual body parts and the timing of the adolescent growth spurt across these individual parts is not uniform. Overall, the change in height at adolescence is due to an increase in trunk length more than an increase in leg length (Eveleth, 1978). The increased rate of change in foot size tends to begin earliest of all, followed by leg length and then trunk length. However the growth spurt "take off" time for these body dimensions is only separated by a few months (Marshall and Tanner, 1986). Changes in upper limb length occur on a similar timescale to changes in the rate of growth of the legs.

There are other notable changes during the adolescent growth spurt. In addition to the rate of change of height, the rate of change of weight increase can also be tracked. Children reach a peak weight velocity (PWV) during the adolescent growth spurt, followed by a negative acceleration as annual weight change moves towards zero. Additionally, the overall proportion of muscle to body fat changes notably: "in boys the rate of growth of muscle in the limbs becomes maximal at approximately the same time as peak velocity in stature. The rate of gain in fat changes in the opposite direction" (Marshall & Tanner, p. 201). The density of muscle as opposed to body fat means that the adolescent growth spurt implies both a change in height and an accompanying change in body density.

2.3 Resulting changes in centre of mass

The changes in height accompanied by changes in weight and changes in fat/muscle ratio mean that the position of centre of mass as well as the positions of individual limb centres of mass change at this time. The centre of gravity is where the sum of the gravitational forces (proportional to their mass) of each individual part of the body are added together to make one resultant force and the point at which this force acts is taken to be the centre of gravity.

The position of the centre of body mass is constant through inversions and rotations of the body, whereas the centre of gravity is not (lower parts of the body experience a slightly stronger gravitational pull than upper ones). Both of these terms will be used throughout this thesis. Centre of body mass is usually equivalent to, or slightly above the body's centre of gravity (Dyson, 1977). Children's centre of body mass is slightly higher than that of adults, because of the difference in body proportions. In adulthood, the muscle density and bone length of the legs accounts for more of the total body mass. The centre of body mass is consequently slightly lower.

3. *Biomechanics of movement*

3.1 Stability

The morphological changes discussed above must have an effect on every movement that a child makes. We must be able to maintain a stable posture where muscular force counteracts the effects of gravity on the body. We do not spend our lives working to **counteract** gravity, however. It is a feature of our environment and in the same way as our visual system uses the structure in light, our motor and vestibular systems **use** the effects of gravity. Walking is often described as controlled falling: we introduce instability in order to move. The importance of the changes during the adolescent growth spurt for static and dynamic control of posture are the subject of this section.

Height, weight, the position of centre of body mass, as well as the centres of mass of individual body parts are important factors in terms of stability. An individual should be able to maintain a stable posture provided that a vertical line drawn through their centre of gravity falls within the base of support and additionally provided that they have the muscular strength to resist the gravitational forces acting upon them. The individual's ability to *maintain* this stable posture depends on the area of their base of support (one leg, two legs, two legs and a stick), the height of their centre of gravity (standing, squatting), the size of the angle from the vertical through which the individual must lean before their centre of gravity is outside the base of support and finally, their weight (Dyson, 1977). For example, a small, light child with a higher centre of gravity proportional to total height has less stability than a tall, heavy adult with a lower centre of gravity. However, stability while at rest is only a very small factor in an individual's ability to perform actions. To examine this, the effects of movement must be considered.

3.2 Moments of inertia.

Both the height of the individual, their mass and the relationship between the two during movement form an important constraint on possible action. This relationship is exploited in numerous sports in a manner that makes it easier to explain. For example, light, pre-pubertal girls of small stature tend to form the top few percent of female Olympic gymnasts. The combination of stature and mass tend to result in lower than usual moments of inertia. The moment of inertia is defined as the mass of the body multiplied by its acceleration about the axis of rotation (Adrian and Cooper, 1995).

The greater the moment of inertia of a body, the greater the internal (muscular) forces that will be required to counteract the external forces acting to rotate it. Alternatively put, a smaller moment of inertia will facilitate rotational movements: the young female gymnast finds it easier to vault, somersault and move on asymmetrical bars than does a taller female with a higher Body Mass Index (ratio of body mass in kilograms to height in metres squared).

Similarly, discus throwers, shot putters and hammer throwers tend to have much higher body mass indices and are thus able to utilise their angular momentum to project objects by using their own relatively high moments of inertia.

A change in the centre of mass of, for example, a limb has a number of implications. During the adolescent growth spurt, bone length increases. The muscle attached to the bones must also lengthen and additionally, they must increase their output. This is because the moments of inertia of the limb increase, necessitating greater effort to move it. However, at around the time of the growth spurt both the length (associated with changes in bone length) and the cross-sectional size of limb muscles increase. As a result, leaning forward with the arm stretched out will result in an increase in the forces acting on the limb and will require an increase in the internal forces necessary to maintain balance and position.

3.3 Effects of system change.

Given the changes that take place during adolescence and the effects of forces acting on the human body, what can be said about the relationship between the two? When planning and performing an action, limb length, weight and strength must be taken into account and when these are changing rapidly, problems may arise in doing so. However, in addition to this, the external forces that act on the individual during any movement must also be accounted for and the action of these forces will change in line with the changes in height, weight and the fat/muscle ratio. As a result, during the adolescent growth spurt, the child must use vision as well as proprioception to recalibrate system parameters that include not only their length of reach but also the effects on any movement of changing moments of inertia. It has been suggested that these changes would result in an extensive period of adaptation (Jensen, 1981).

4. *Affordances*

4.1 The Actor-Environment relationship.

While we take account of the forces that act on us as we interact with our environment, this knowledge does not take the form of a calculation using information about one's height, one's weight and the laws of mechanics. J.J. Gibson's explanation of the relationship between perception and action is a useful way of thinking about the interaction between humans and their environment: interactions which, to an observer, can be described as actions or intentional movements. Gibson (as cited in Reed, 1982) wrote of the actions which the environment afforded the individual and of the sensitivity of the individual to these affordances. He pointed out that affordances were unique to each individual and were a function of the characteristics of the object perceived and the physical characteristics of the perceiver. However, he was keenly aware that animals are not immutable and consequently, neither are the range of affordances which they can detect. He stated that: "perception is based on sensitivity, but that sensitivity improves with growth, living, and training" (Gibson, as cited in Reed, 1988, p. 192).

Thus, a useful way to examine motor development is to examine what affordances children detect at different stages of growth, or by the same child at different stages of growth. By altering the environment and observing different children's responses to the change, we can learn about perceptuo-motor development as well as about the nature of affordances.

4.2 The relationship between biomechanics and affordances.

An animal moves about in its environment, detecting properties of that environment and structuring its actions with respect to these properties. However, although the animal does not (usually) know about the laws of mechanics, nor that its legs are 97cm in length with a number of joints, its actions are nevertheless constrained by these facts. An affordance detected by an animal contains within it a set of constraints. These constraints are both properties of the animal (leg length, for example) and of the environment (mass of the object, for example).

An example of an examination of the properties of the animal and the affordances that they could detect was the experimental study of stair climbing by Warren (1984). Warren proposed that the participants in his study were sensitive to the climbability of stairs of different dimensions and that the climbability they detected was a function of their leg length. Long legged observers were willing to attempt to climb steps with much higher riser heights than were short-legged observers. However, when riser height was expressed as a proportion of leg length, a similar number (which Warren termed a dimensionless number) was obtained for all observers. It appears that an invariant relationship between characteristics of the actor and properties of the environment exist which can be detected by an actor, suggesting that it is the invariant which is perceived, not the absolute size and shape of the object considered (Carello et al, 1989). The participants in the experiment were apparently making their judgements of climbability based on an intrinsic property of their own system: their leg length. This also leads to the possibility that biomechanical models of animal/environment systems could be made which would allow the prediction of action boundaries.

So, for example, not only is it possible to study the child's perception of affordances at different stages of development, it is also possible to create a biomechanical model of the limits of a particular action for a particular child and compare their performance with this model.

Numerous experiments examining affordances and properties of the actor which determine the set of affordances that they detect followed Warren's (1984) study. These experiments examined actions such as reaching (Carello et al, 1989), walking through apertures (Warren & Whang, 1987), choosing seats (Mark, 1987) and crossing barriers (Pufall & Dunbar, 1992). Increasingly, this type of experimental approach has been used to examine the development of skill in infants and children.

4.3 Affordances and development.

The relevance of Gibson's theories in examining perceptual and perceptuo-motor development is clear. There is apparently no limit on the things we can learn to "see", once we have begun to detect invariant properties of our environment. Even as adults, we can learn the ability to distinguish pictures in apparently random sets of dots. Affordances are invariant properties of the environment that relate to our own physical structure. However, this physical structure changes as we develop. The child who grows a few centimetres over a period of time doesn't need to re-learn stair climbing. They simply need to recalibrate the environment/action system relationship. The only way to do this is to continue to move and act and an interesting theme to pursue is whether a recalibration is general, affecting all movement or whether specific actions need individual and separate recalibration. If the latter is the case, less practised actions would show a recalibration lag relative to more practised actions.

There have, in fact, been an increasing number of studies of the perception of affordances by infants and young children which demonstrate that even very young infants can utilise the information in their environment to structure their actions. Yonas & Hartman (1993) looked at the likelihood of seated infants reaching towards toys and found that the likelihood of the infant attempting a reach decreased once the object was placed outside the infant's predetermined prehensile space. These studies have also studied changes in infants' actions based on motor development. Infants who can maintain seated balance while leaning forward attempt reaches towards more distant objects than do children who cannot maintain seated balance. This highlights the likelihood that infants include the effects of developmental change in moments of inertia in their calibration of reaching actions.

Other developmental studies have examined older children's detection of affordances. In particular, Plumert (1995) and Plumert & Schwebel (1997) investigated children's ability to detect their potential for action in different experimental situations. These included reaching forward, reaching upward, stepping across gaps and passing under barriers. They found that six and eight year old children tended to overestimate their abilities in these situations. McKenzie and Forbes (1992) found that nine and especially twelve-year-old boys overestimated the height of steps that they could climb.

These overestimations are likely to occur for a number of reasons. First, the constraints imposed by the experimental situation may result in overestimation. Given the number of skeletal degrees of freedom, it is possible to choose an action from a constellation of possible actions. To some extent, the environment will narrow the range of possibilities: for example, hand orientation in reaching is determined by the shape of the object to be grasped (Goodale, 1991). In a situation where an object must be placed on a shelf higher than the total height of the actor with arm raised and standing on tiptoe, the option to jump remains. Typical experimental situations preclude this option. However, it remains as a detectable affordance of the environmental layout available to the actor. As such, it is not surprising that humans, both adult and children, tend to overestimate (Rochat & Wraga, 1997). The second reason why overestimations may be apparent in young children is because, as mentioned previously, an increased tendency to overestimate is likely to be linked to attempting movements at or beyond the limit of current ability in order to exploit physical development.

4.4 Methodology.

In order to address the questions raised in the discussion above, it is necessary to review the kinds of experimental approach that have been used by previous researchers to arrive at the conclusions described above.

There appear to be two approaches to the study of children's perception of affordances.

Yonas & Hartman (1993) and McKenzie et al. (1993) typify the first, where children are encouraged to perform certain actions. The likelihood of the child performing the action is taken as a measure of the child's knowledge of the limits of action. This kind of measure is preferred by Heft (1993) who stated that asking for judgements of reachability are reflective and analytical rather than purely perceptual and as such are a source of error. However the overestimates discussed above were still observed by McKenzie et al. (1993) using this method - they found that the children often attempted reaches which resulted in them falling over. Additionally, Heft's method should produce random error, whereas overestimates seem to make up the vast majority of errors observed.

The second approach, used predominantly in this thesis, involves asking participants to make judgements of their abilities in different experimental situations. It is unlikely to be any more or less valid than the first method, since the two approaches are simply different means to a similar end. Warren's (1984) experiment of stair climbability used observer's verbal judgement, as did Carello et al. (1989) in judgements of reachability and

Mark et al. (1990) justified the use of this method when they examined observers' knowledge of the height of surfaces on which they could sit. It is necessary when using this kind of approach to ensure that the judgements are made without trial and error actions: subjects are allowed to view the experimental set up, but not allowed to attempt the action until all judgements are made. This is because subjects whose estimates differ widely from their actual performance recognise this error with some surprise as soon as they attempt the movement and quickly start changing their estimates in line with the feedback from their performance. This was observed in a pilot study that preceded the research described in this thesis, where adult volunteers judged whether balls placed at different distances were graspable.

Previous experimental work has also used anthropometric data to construct models of certain actions. For example, leg length is important in examining step length. However, it is unlikely that a perfect concordance between measured body dimensions and limits of action is achievable, since, as indicated above, there are other variables which affect performance. Moments of inertia for specific body parts as well as for the whole body limit the number of movements possible in a given posture and so do flexibility and muscular strength.

6. Rationale and Review of Experimental Work.

A series of questions has arisen from a consideration of the work reviewed. First of all, no experimental investigation of the claim that adolescent children are poorly coordinated has ever been carried out. Since one of the key changes in adolescence is the change in height, weight and muscle mass, it seems worthwhile to study the role that these changes may play in maintaining coordinated movement during adolescence.

Previous studies have also indicated that young children tend to overestimate their abilities more than adults, but although children up to age twelve have been studied, no study has examined the very time when the child begins to take on an adult appearance, namely adolescence and puberty. The question that arises is whether there is a detectable transition between childhood and adulthood in terms of perceptuo-motor control and a useful way to study this is by studying adolescents' judgement of their movement abilities.

The nature of changes in height, weight and muscle mass during adolescence have been discussed in terms of their effect on static and dynamic balance. Taking this into account, a more in-depth examination of the perceptuo-motor control of children in this age group is worthwhile, since any differences seen in this age group may be due to a necessity to recalibrate in terms of new limb lengths (and consequently a change in eye-height), but the differences may also be attributable to a necessity to recalibrate in terms of changes in moments of inertia and ability to maintain dynamic balance during actions.

A number of different approaches to the investigation of these topics are present in the seven experiments described in the following chapters. The thesis can be divided in terms of two separate approaches. The first, as described in chapters two, three, four and five, examines a group of boys aged twelve and thirteen. These children were selected as most likely to be undergoing an adolescent growth spurt, bearing in mind that the acceleration in rate of change of height/year begins in boys at, on average, age 12.5 but has returned to the previous level one year later (age 13.5) (Faulkner & Tanner, 1986). The performance of boys in this age group was compared to the performance of a group of younger boys (aged ten and eleven) and a group of older boys (aged fourteen and fifteen). These experiments covered children's prediction of their abilities in a number of situations.

The first experiment used a similar design to an experiment reported by Carello et al. (1989) where adults were tested on their ability to predict their maximum reach along a number of surfaces which would have been between ankle and waist level for the standing subjects. This allowed comparison between the affordances for reaching detected by boys in the different age groups, as well as providing a measure of validity: the children should all have been sensitive to the different affordances of the different surfaces - random estimates would be easily detected. This particular experiment not only examined children's detection of the affordances of the surfaces, but also necessitated them taking into account changes in, for example, arm length due to growth as well as changes in moments of inertia. The children were allowed to reach quite far forward and thus they needed to be sensitive to the point of muscular reversibility - passing this point would result in a horizontal movement of their centre of gravity which would result in instability.

The second experiment, described in chapter three, involved the same three groups of children making estimates of their reaching ability. This time, however, a similar experiment to one described by Plumert (1995) was used. Children were asked to predict their ability to reach to a shelf above them. The experiment was equivalent to experiment one, but with children moving their centres of gravity vertically upwards rather than horizontally. This provided less potential for instability and was intended to examine whether any coordination problems observed in the adolescent group were due to height (and hence eye-height) changes or to additional problems dealing with changing moments of inertia.

The third experiment, described in chapter four, was similar to another experiment described by Plumert (1995). Children were asked to perform a locomotor task: judging whether they could cross gaps created by moving two surfaces apart. This was intended to examine whether children were sensitive to the consequences for movement of changes in leg length.

The fourth experiment draws on an experimental tradition in the motor skills development literature - static balance has been studied in development by using a stadiometer, where the child places one foot one either side of a platform which can tilt and they shift their weight until the platform is held in equilibrium (Rarick, 1982). Dynamic balance is normally tested using a balance beam task (Proteau, Tremblay & DeJaeger, 1998). Experiment four used a balance beam task to identify whether the changes in height, muscle mass and moments of inertia at adolescence would affect the child's ability on this task.

The remaining three experiments, described in chapters six, seven and eight use a different approach. In this case, only children aged twelve and thirteen were studied, being the group most likely to be undergoing a growth spurt. Over one hundred children were recruited and measured during the spring term. Following a six-month interval, at the beginning of the new school year, the children were measured again and performed three tasks. The aim of these experiments was to investigate the role that changes in height accompanying a growth spurt would have on the children's ability to detect certain affordances.

The fifth experiment, described in chapter six, used the same design as the first experiment described above - children judged their ability to reach forward to different height surfaces. The sixth experiment, described in chapter seven, used the same design as the second experiment - children judged their ability to reach upward to high shelves.

The eighth and final experiment used a new design. Children were asked to make judgements of their reaching ability using two long poles with hooks on the ends. This was intended to highlight any changes in moments of inertia associated with the growth spurt which might result in children who had recently grown a lot finding it much harder to recognise their point of muscular reversibility.

Chapter nine, the final chapter, is a general discussion and conclusion of the implications of the findings of the eight experiments described in this thesis, with specific reference to the issues discussed above and the questions which arose from a consideration of these issues.

Chapter Two

Estimating reachable distance in a forward leaning task: Playing Shove Ha'penny.

Gibson enumerated many affordances which different environmental layouts may offer to the animals which inhabit them (Gibson, 1979). In addition to information about the crossability of gaps and the characteristics of different surfaces that might/might not afford locomotion, Gibson mentioned surfaces which might provide support for useful objects and the manipulations which the objects on them may offer (Gibson, 1971). However a great deal of research on reaching has concentrated on biomechanical properties of reaching movements and the effects on accuracy of manipulating the speed and difficulty of the movement (Fitt's Law) (Jeannerod, 1984; Wing, Turton and Fraser, 1986). This research tends not to take Gibson's approach into account, so ways in which the relationship between the environment in which the reach takes place and the physical characteristics of the individual performing the movement determines the kind of movement made is not considered.

In 1989, however, Carello et al. published a comprehensive account of the role of visual perception in deciding which objects were reachable and which were not. In a series of experiments, they examined observer's judgements of reachability while seated or standing and to single and multiple height surfaces. They proposed that each individual's judgement of reachability will be unique. This proposal is based on Gibson's (1979) suggestion that affordances are based upon properties of the environment, but only as they relate to the individual perceiving them. A large gap may only afford crossability if you have very long legs, for example. To test this proposal, Carello et al. (1989) compared the performance of short and tall observers. Similarly to earlier studies by, for example, Warren (1984), they observed that reachers appear to detect information present in the environment to guide the actions they attempt - and that actions based on this information differ depending on factors including the height of the observer.

This type of research is not confined to adults. Yonas and Hartman (1993) studied the relationship between developing levels of balance while seated and the likelihood that young infants would attempt reaches towards objects at different distances. Infants who were able to maintain balance while leaning forward were more likely to initiate reaches towards more distant objects than were infants who were still unable to maintain balance while leaning.

However, Plumert (1995), using a number of experiments including one similar to the forward reach in Carello et al. (1989), noted that 6- and 8-year old children tended to overestimate their ability to perform tasks rather more than did adults. Similarly, McKenzie et al. (1993) noticed, during a similar experiment to that carried out by Yonas & Hartman (1993), that young children attempted to grasp even objects well outside their reach. So although adults and young children are capable of identifying their action capabilities with respect to different environments, children may do so either less accurately or at least differently to adults. The developmental advantage of overestimating abilities in certain situations has been discussed in the Introduction.

With respect to rapidly growing adolescents, the idea of studying the actions they believe they are capable of attempting (e.g. maximum reach while standing) are of particular interest. The increase in length of limbs and trunk are accompanied by a change in muscle mass and hence a change in centre of mass (centre of gravity) both for individual limb segments and for the body as a whole. As pointed out by von Hofsten (1993) "the upcoming forces and momenta indiced by a movement have to be counteracted before they upset the flow of action and the balance of the body(p.253)". When reaching for an object, the actor must take into account both the length of their reach and their ability to react correctly to the change in force and momentum. In circumstances where there has been a recent change in both limb length and centre of mass, it may be more difficult for an individual to make an accurate judgement of their ability in a given situation.

In order to examine this possibility in more detail, it would be necessary to ask children before, during and after the adolescent growth spurt to make judgements, in this case about their maximum standing reach. As discussed in detail in the Introduction, the changing rate of growth at puberty has been widely discussed over the last few decades (Eveleth & Tanner, 1976; Marshall & Tanner, 1986). It is generally agreed that an identifiable change in height velocity takes place around the ages of 12 or 13 years in boys and a slightly less easily identifiable change takes place in girls one or two years earlier. This change in the rate of overall growth is echoed by changes in the rate of growth of individual body parts, in particular leg length, trunk length, arm length and foot size. Eveleth & Tanner (1976) indicate that, on average, boys add 10.5 cm to their height between their 10th and 12th birthdays, but add 13.4 cm to their height between their 12th and 14th birthdays. This is the Peak Height Velocity. The rate of change of height then begins to slow again, with an average of 11.4 cm being added between their 14th and 16th birthdays. Marshall (1975) has also observed that most growth takes place during summer months.

Given than an individual perceives affordances based on their own physical capabilities, changes such as these are likely to result in a child having to recalibrate their knowledge of what actions are possible. In addition to the effect on reach of, for example, a change in limb length, children also have to take into account changes in muscle size and mass and related changes in centres of mass and moments of inertia of their body and individual limb segments. Thus, any study of the changing affordances offered by their environment to a growing child is effectively a study of a recalibration process.

Carello et al (1989) varied the relationship between forces of gravity acting on the body and the length of reach possible by varying the heights of the surfaces to which the reach must be made. They looked in detail at the reaching possibilities afforded by different height surfaces to adults of different heights. However, such an experiment carried out with children undergoing changes associated with the adolescent growth spurt could throw light on how these children recalibrate to deal with these changes and indeed, on how all humans deal with temporary and permanent changes in their physical ability.

The present experiment is thus a modification and extension of the Carello et al. (1989) design and looks in detail at the ability of boys aged between 10 and 15 years of age to judge their maximum standing reach at four different surface heights. The sample is restricted to boys because of the relative ease of identifying a growth spurt in boys and the relative difficulty of identifying a growth spurt in girls. The experiment was carried out in the first months of the new school year, since growth was most likely to have occurred during the summer months (Marshall, 1975). Additionally, children were recruited from a number of schools in different areas of Glasgow, chosen to represent differing socioeconomic backgrounds, since this is often a factor in levels of physical fitness and activity. Where possible, primary schools were feeder schools for secondary schools which took part.

Since the children in the 12 and 13 year age group are most likely to be undergoing a growth spurt (Marshall & Tanner, 1986), they are most likely to have difficulty in making predictions of their reaching ability based on their current limb lengths, centres of mass and moments of inertia in relation to the environment presented to them. Taking this into consideration, the following four predictions were made.

First, Carello et al. (1989) found that adults of different heights judged their maximum reach accurately, taking into account their own physical proportions. Since older children are likely to be taller than younger children, the mean heights for children in the 10 and 11 age group, the 12 and 13 age group and the 14 and 15 age group will be different. Children should predict their maximum reach based on their own height and consequently there should be a difference in predicted reach and actual reach in proportion with the differences in mean height between the groups.

Second, children in the three age groups will differ in terms of the relationship between their predictions and their actual reach. Carello et al (1989) found that adults overestimate their abilities slightly on this kind of task, but especially at the lowest surfaces. Plumert (1995) found that 8-year-old children did not overestimate as much as did 6-year-old children on a similar task and that both groups overestimated their abilities more than did adults. In this case, it is predicted that there will be differences between the three age groups in terms of degree of overestimation, with overestimation decreasing as age increases.

The third prediction is based specifically on the fact that the 12 and 13 year olds are most likely to be growing rapidly and thus should find it more difficult to make accurate judgements of their reaching ability than children in the other two age groups. It is thus predicted that the relationship between predicted and actual reach will be closer for children in the 10+11 and 14+15 age groups than for children in the 12+13 age group.

The fourth prediction is based on an idea proposed by Carello et al. (1989), but is also linked to a point introduced by Warren (1984). When a specific movement is no longer specified by the match between the environmental layout and the action capabillities of the animal, a critical point is reached when the animal is likely to switch to a different movement. Carello et al. (1989) proposed that standing reachers are sensitive to a "region of reversibility(p.45)" - a critical point beyond which it is not possible muscularly to reverse the reach to regain an upright posture. Since recognition of this point depends on an accurate use of the mass and length of the body and limb segments when performing an action, the 12 and 13 year old group should be less sensitive to this region - being more likely to produce mistrial errors where they lose balance.

Method:

Participants:

75 participants were recruited from Primary and Secondary Schools in the Glasgow City Council Education Department area. Once each head teacher had agreed that the study could take place, a contact teacher identified a number of boys who would meet the specified criteria. These were as follows:

Boys eligible to take part had to be aged greater than 10 years of age and less than 12 years of age (Primary Schools) at date of testing, or less than 16 years of age (Secondary Schools) at date of testing. Teachers were informed that the aim was to obtain roughly equal numbers of boys in each of three age bands: 10/11, 12/13 and 14/15. It was explained that the aim was to study boys likely to be before, during and after the adolescent growth spurt. Teachers were asked to base their selection on the boys' age (not their size), but this proved difficult as not all teachers had easy access to this information, so in the case of the Secondary schools, boys were chosen in equal numbers from the first four years. Children with known and diagnosed coordination or movement difficulties were excluded from the sample.

Parental consent was obtained for the boys identified as suitable by the contact teacher. Table 2.1 summarizes the boys who took part in this experiment.

Table 2.1: Participant details.

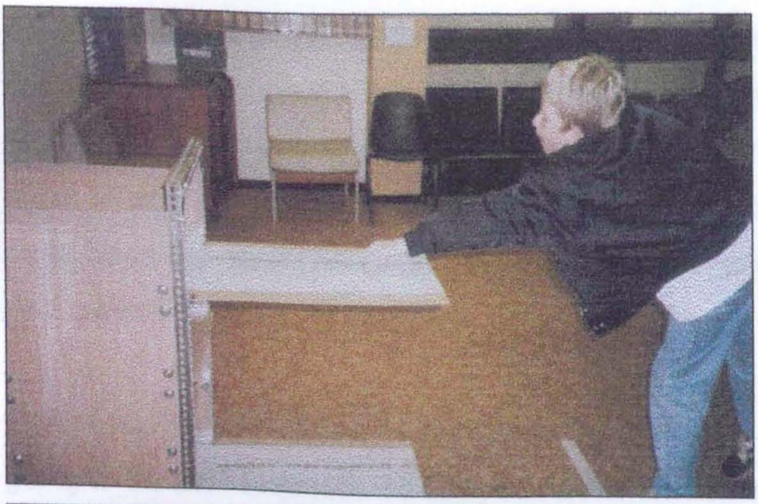
Age Group	Mean Age in years and months	Age Range (y/m)	Mean Height (cm)	sd	range (cm)
Age 10+11, n = 34	11 years, 1 month	10/0 - 11/11	148cm	6.0	136-160
Age 12+13, n = 19	13 years, 1 month	12/0 - 13/11	153cm	7.1	136-164
Age 14+15, n = 22	15 years	14/0 - 16/0	170cm	9.2	152-185

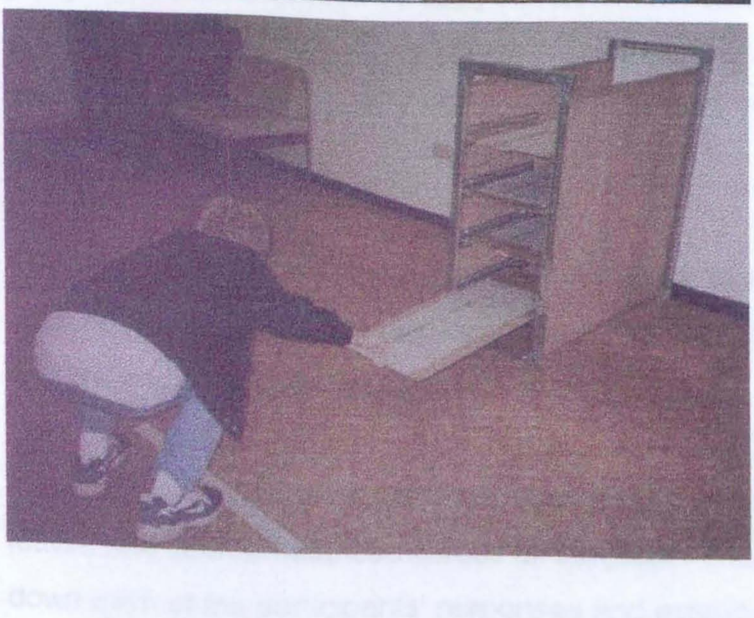
Materials:

The test apparatus consisted of a set of 4 movable surfaces, which when fully extended measured 60cm in length and were 20, 40, 60 and 80cm above floor level respectively. A photograph of the apparatus can be seen in Figure 2.2 below. Carello et al. (1989) noted that their test was conducted with only women participants, as they felt that men had difficulty making reaches at floor level. They used zero, 25cm, 75cm and 100cm as their selected heights. However, pilot data indicated that children in the 10+11 year old group had foot to hip measurements of only 85-90 cm, compared to 105 cm in the oldest boys. Because of this and because only males participated in the present experiment, floor level and 100cm heights were not used. Four sets of card, each marked with a different set of 20 randomised letters at 2cm intervals, up to a maximum distance of 40cm from the front of the surface were also used. These fitted in retaining pieces on the front of each surface height, ensuring that they were consistently located on top of the surface. Randomised letters were used to ensure that, since each participant saw a different set of letters on each surface height on each of four trials at each surface height, they would make an independent judgement of distance on each trial and not simply memorise and repeat the previous judgement.

A start line was taped to the floor 70cm away from the front of the fully extended surfaces and participants were requested to stay behind this start line at all times during the experiment. The target of the reach was a small cylindrical object 1cm in depth and 4cm in diameter.

Figure 2.2: Photographs of the apparatus used in the present experiment. The four extendable surfaces can be seen in the bottom picture. The boy seen in the photographs was aged 11.





Procedure:

Participants were initially told that they would be taking part in two experiments designed to test their judgements of height and distance. Half of all participants completed the present experiment first and half completed another experiment first and the present experiment second. Participants were asked to approach the start line and wait while the experimenter explained the rules of the test to them. The experiment gave each participant the following instructions:

"This is a kind of guessing game. Before you begin, I'll tell you a few things about it. The aim is for you to put this object down as far away from you as possible on each of these boxes. There are a few rules about how you do this. You can't touch the floor with your hand or foot on the other side of this line while you're trying to place the object and you must be able to stand up again without losing your balance after you have put the object down. You must place the object down on one of these marks and not throw or push it. Any questions about these rules?

Before you do any of that, I want you to tell me which mark you think you are going to be able to reach. I'll ask you four times at each of these four different heights - that's sixteen times altogether - but it's important that you don't try out the moves until I ask you to at the end. Have you any questions about that or would you like to start?

OK, here's the first level - the marks each have a letter name beside them. Look at the marks and tell me, using the letter name, which one is the farthest you could put this object down on."

The order of presentation of both surface height and set of randomised letters was counterbalanced across all subjects. The experimenter marked down each of the participants' responses and extended or retracted the surfaces as appropriate, placing the letter card on top. After all the judgements had been made, the experimenter handed the target object to the participant and briefly reminded them that they should not cross the start line, or place their hand on either the floor or the surface to keep their balance. The participant then performed four actual reaches at each surface height (again order of presentation was counterbalanced) and the experimenter noted down which mark the target object was placed on. Additionally, all trials where subjects lost their balance and placed either their hand or foot over the start line were recorded as mistrials. When this occurred the experimenter invited the participant to try again at that surface height to make up the correct number of valid trials.

Results:

Data resulting from this experiment were analysed in terms of their relevance to a number of key themes:

- actual reach of children in the three age groups was examined first;
- following this, the predicted reach of the children was examined;
- the relationship between predicted and actual reach was examined in terms of both differences between predicted and actual reach and correlations between predicted and actual reach and finally,
- mistrials, where children lost their balance during a reach, were examined in terms of differences between age groups.

Measurements of actual reach:

When the mean actual reach for children in the three age groups was examined, performance differences could be seen. This is illustrated in Figure 2.4 below, with the Mean Actual Reaches for children in each age group and at each surface height listed in Table 2.3. A 3 x 4 Repeated Measures ANOVA with a between-subjects factor of Age Group (10+11, 12+13 and 14+15) and a within-subjects factor of Surface Height (20cm, 40cm, 60cm and 80cm) was carried out. There was a significant main effect of Age Group ($F(2,72)=27.97$, $p < 0.0001$) and Bonferroni tests ($p < 0.05$) revealed that the 10+11 year old children reached significantly less far than the 12+13 year old children who, in turn, reached significantly less far than the 14+15 year old children at all surface heights.

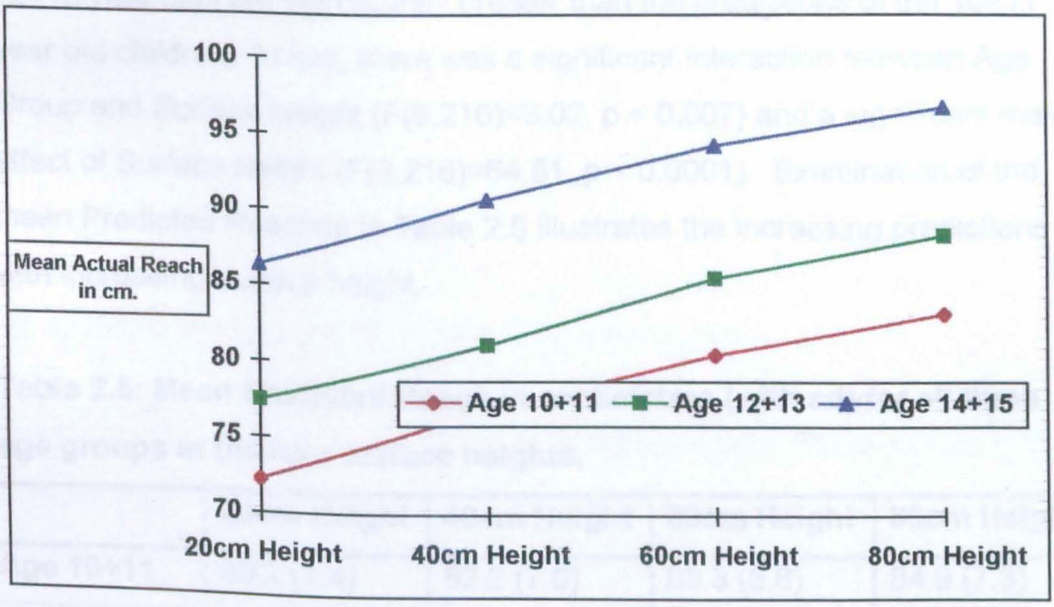
There was also a significant main effect of Surface Height ($F(3,216)=270.1$, $p < 0.0001$). Examination of the means in Table 2.3 shows that reach increased as surface height increased.

There was no significant interaction between Age Group and Surface Height (F(6,216)= 0.32, n.s.) and this can be seen on inspection of Figure 2.4: the lines for the three age groups are parallel.

Table 2.3: Mean Actual Reach in centimetres (with sd) for all three age groups at the four surface heights.

	20cm Height	40cm Height	60cm Height	80cm Height
Age 10+11	72.1 (6.6)	77.0 (5.7)	80.6 (5.8)	83.3 (5.6)
Age 12+13	77.4 (6.2)	81.2 (6.3)	85.6 (6.7)	88.3 (6.3)
Age 14+15	86.3 (8.9)	90.7 (9.2)	94.3 (8.9)	96.8 (8.5)

Figure 2.4: Mean Actual Reach at each Surface Height



Measurements of Predicted Reach:

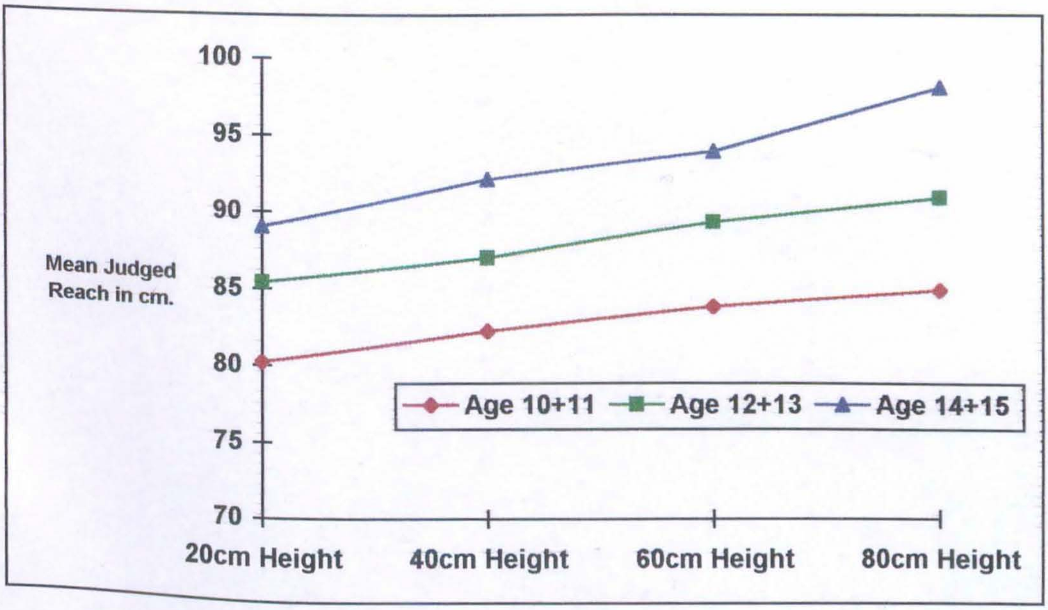
A slightly different pattern of results became apparent when the children's predicted reaches were examined. Mean Predicted Reaches are illustrated in Figure 2.6 and means and standard deviations can be seen in Table 2.5. A 3 x 4 Repeated Measures ANOVA with between-subjects factor of Age Group (10+11, 12+13 and 14+15) and a within-subjects factor of Surface

Height (20cm, 40cm, 60cm and 80cm) was carried out on the children's predicted reaches. Once again, there was a significant main effect of Age Group ($F(2,72)=15.47$, $p < 0.0001$). However, the mean Predicted Reach for children in three age groups were more similar than their actual performance on the task. Bonferroni tests ($p < 0.05$) showed that at both the 20cm Surface Height and the 40cm Surface Height the 14+15 year old children's estimates were only significantly greater than those for the 10+11 year old children. There were no significant differences between the 14+15 year old children and the 12+13 year old children or between this group and the 10+11 year old children. However, by the 80cm Surface Height, the predictions of the 14+15 year old children are significantly greater than the 12+13 year olds and the 10+11 year olds and in turn, the predictions of the 12+13 year olds are significantly greater than the predictions of the 10+11 year old children. In fact, there was a significant interaction between Age Group and Surface Height ($F(6,216)=3.02$, $p < 0.007$) and a significant main effect of Surface Height ($F(3,216)=64.81$, $p < 0.0001$). Examination of the mean Predicted Reaches in Table 2.5 illustrates the increasing predictions with increasing surface height.

Table 2.5: Mean Predicted Reach in centimetres (with sd) for all three age groups at the four surface heights.

	20cm Height	**40cm Height**	**60cm Height**	**80cm Height**
Age 10+11	80.2 (7.4)	82.2 (7.0)	83.3 (6.8)	84.9 (7.3)
Age 12+13	85.4 (7.2)	87.0 (6.6)	89.3 (6.7)	91.0 (7.3)
Age 14+15	89.0 (8.7)	92.2 (7.7)	93.9 (7.5)	98.1 (8.8)

Figure 2.6: Mean Predicted Reach at each Surface Height for children in the three age groups.



Relationship between predictions and actual reaches:

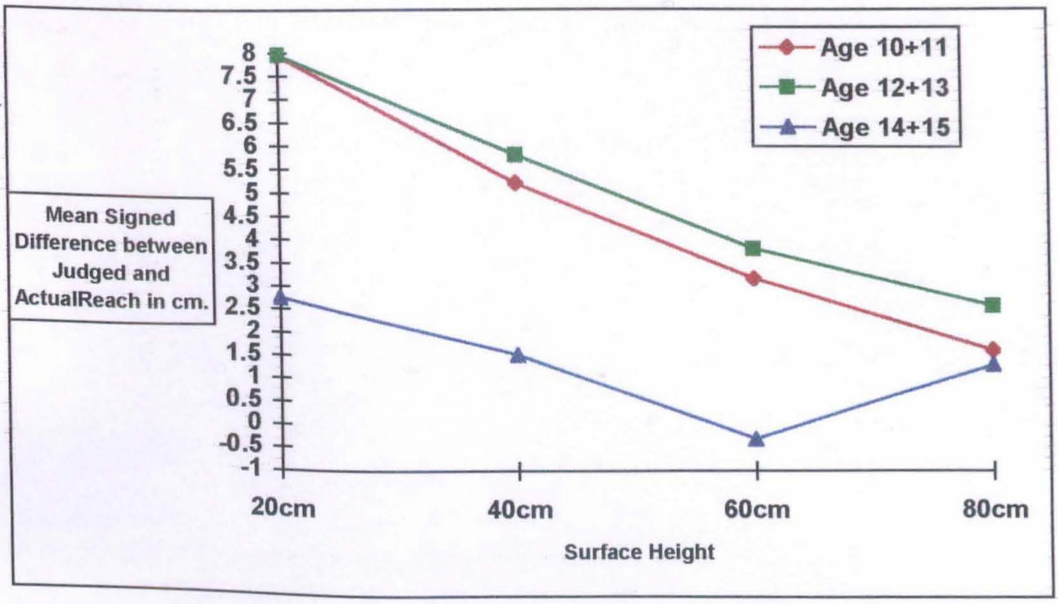
Given that the mean actual reaches for children in each of the groups differed significantly between the three age groups, but the age group differences beween predicted reaches was not so clear, a closer examination of the relationship between predictions and actual reach for children in the three age groups is likely to be informative.

Signed differences were obtained by subtracting actual reach from predicted reach. Examination of the resulting signed differences between predicted and actual reach (effectively indicating whether the groups tended to over- or under-estimate) showed a difference between the three age groups (Figure 2.8). There was no significant effect of group, but there was a significant effect of surface height ($F(3,216)=23.70$, $p>0.001$) and a significant group x height interaction ($F(6,216)=2.43$, $p>0.05$). Bonferroni tests ($p < 0.05$) showed that the signed difference between predicted and actual reach was significantly less for the 14+15 year old children than for the other two groups at the lowest surface height ($p<0.05$). There were no significant differences between the age groups at any of the other surface heights. Examination of the mean signed difference scores (Table 2.7) shows that these tended to be very similar for the 10+11 year old group and the 12+13 year old group, but notably less for the 14+15 year old group. However the scores for all three groups come closer together as surface height increases, reflecting the lack of significant group differences on the 40, 60 and 80cm surfaces.

Table 2.7: Mean Signed differences (with sd) between predicted and actual reach for children in the three age groups at the 20, 40, 60 and 80cm surface heights.

	20cm Surface Height	40cm Surface Height	60cm Surface Height	80cm Surface Height
Age 10+11	7.94 (6.59)	5.19 (5.98)	3.12 (6.04)	1.59 (7.02)
Age 12+13	7.95 (7.59)	5.79 (7.11)	3.76 (7.09)	2.55 (6.65)
Age 14+15	2.75 (7.74)	1.50 (7.53)	-0.32 (7.59)	1.27 (6.71)

Figure 2.8: Mean Signed Difference for the three age groups at all surface heights. This is a comparison of the direction of the error (i.e. under or overestimate).



The signed difference scores indicated that the youngest children seemed to be predicting that they could reach rather more than they could. However, in line with the analysis carried out by Carello et al. (1989) a closer examination of the overall pattern of underestimates and overestimates was carried out. The percentage of over- and under-estimates and accurate scores for children in each age group is shown in Table 2.9. This shows that over-estimates decrease with age and under-estimates increase, but also that the percentage of accurate scores is lowest for children in the 12+13 year old group. A significant Chi-square (χ^2=11.82, p<0.01) carried out on the frequencies showed that there was a significant relationship between age group and nature of prediction.

Table 2.9: Percentage of scores which were over- and under-estimates for each Age Group.

	Underestimate	Zero Error (> ±1)	Overestimate
Age 10 and 11	17%	21%	62%
Age 12 and 13	19%	14%	67%
Age 14 and 15	27%	30%	43%

The investigation of the relationship between predicted reach and actual reach was completed by an examination of the correlations between predictions and actual reachs for each group. Table 2.10 below shows the Pearson correlations (and significance levels) for the three age groups. Since these correlations are a measure which does not reflect the stature differences between the groups, but simply the match between predicted and actual reach, it may be more informative about the nature of the predictions. The Pearson correlations shown in Table 2.10 indicate that there is a much closer match between predicted and actual performance for the 14+15 year old children and 10+11 year old children than for the 12+13 year old children.

Table 2.10: Pearson correlations between predicted and actual reach for children in each age group at each surface height.

	20cm Surface Height	40cm Surface Height	60cm Surface Height	80cm Surface Height
Age 10+11 n=34	0.56 ($p < 0.001$)	0.57 ($p < 0.0001$)	0.55 ($p < 0.001$)	0.43 ($p < 0.01$)
Age 12+13 n=18	0.36 (p = n.s.)	0.39 ($p < 0.10$)	0.44 ($p < 0.06$)	0.53 ($p < 0.02$)
Age 14+15 n=22	0.61 ($p < 0.002$)	0.62 ($p < 0.002$)	0.58 ($p < 0.004$)	0.70 ($p < 0.0001$)

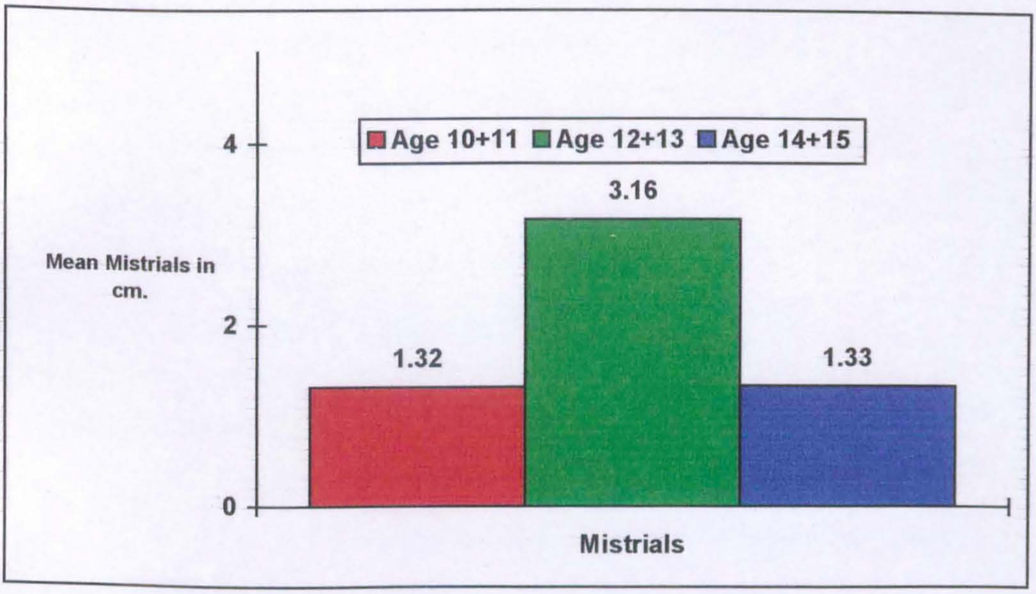
Comparison of Mistrials between age groups:

It was also hypothesised that 12 and 13 year old boys (approximate growth spurt age) would have greater difficulty in identifying the limits of their zone of muscular reversibility due to the recent changes in the centre of mass and moments of inertia for their limbs and body. Thus they would find it more difficult to predict a safe reach and to regain an upright posture following the reach. It has been indicated that the 12+13 year old group were quite likely to overestimate their ability to reach. Were these overestimates combined with balance difficulties?

It was possible to compare the performance of the boys in the 12 and 13 age group with the other two groups with respect to mistrials. These were occasions in which subjects lost balance and crossed the start line, either by putting their hand or foot down on the floor on the far side of the line. Figure 2.11 shows the mean number of mistrials in each of the three age groups.

The 12 and 13 year olds produced more than twice as many mistrials as either of the other two groups. A one-way analysis of variance comparing the three groups was significant ($F(62,2)=7.26$, $p<0.01$). Post-hoc tests (Bonferroni) showed that the mean group score for 12 and 13 year olds was significantly different from the scores of both the 10 and 11 year group and the 14 and 15 year old group ($p<0.05$).

Figure 2.11: Mean Number of Mistrials for each age group.



Discussion

Four predictions were made with respect to the outcome of this experiment. The first prediction was that reach should increase with a child's height and that this should result in children in an older age group with a greater mean height reaching further than children in a younger age group with a lower mean height. Since children should be able to take their own physical proportions with respect to the reaching surface into account, predicted reach should also increase from younger to older children. The second prediction was that the differences between predicted and actual reach should differ between the three age groups. The third prediction was that 12+13 year old children should find it more difficult than children in other age groups to predict their maximum reach accurately, due to the rapid growth spurt occuring around this age. Finally, the fourth prediction was that 12+13 year old children would be most likely to record mistrials, due to a difficulty in identifying the limits of their zone of muscular reversibility.

These predictions will now be examined under the following headings:

- *Measurements of actual reach.*
- *Measurements of predicted reach.*
- *Relationship between predictions and actual reach.*
- *Comparison of mistrials between age groups.*

Finally, the overall implications of the results of this experiment will be discussed with specific respect to the movement abilities of children during the adolescent growth spurt.

Measurements of actual reach:

When the actual reaching performance of children in the three age groups was examined, it could be seen that the first prediction had been supported.

On average, children in the 14+15 age group were taller than children in the 12+13 age group who were, in turn, taller than children in the 10+11 age group. The actual reaches of children in the 14+15 age group were significantly greater than those of children in the 12+13 age group and these, in turn, were significantly greater than the reaches of children in the 10+11 age group. The mean scores also indicated that all children tended perform their longest reaches at the highest surface and their shortest reaches at the lowest surface height.

Measurements of predicted reach:

However, when predicted reach was examined, the differences between the three age groups were less apparent. While the 14+15 year old boys still predicted that they could reach significantly further than the 10+11 year old boys, at the two lowest surface heights (20cm and 40cm) there was no significant differences between the predictions of the 12+13 year old boys with either older or younger groups. At higher surfaces, however, significant differences appear between all three groups, similar to the differences between their actual reaches.

This would seem to indicate that some children are not correctly identifying their ability to reach and that this is particularly the case at the lowest surfaces. In order to investigate this in more detail, it is necessary to look more closely at the relationship between children's predictions and their actual reaches.

Relationship between predictions and actual reaches:

The data were examined to discover whether any one age group had greater discrepancies between predicted reach and actual reach than any other group. When the signed differences were examined, it could be seen that the mean signed difference between prediction and actual reach for the oldest children was quite close to zero, indicating that they were either overestimating slightly or possibly underestimating slightly. An examination of the frequencies of over or under-estimation showed that this was indeed the case: boys in the 14+15 age group overestimated more than they underestimated, but they had the highest number of accurate trials and the highest number of underestimates of the three groups. Similarly, the correlations between their predictions and actual reaches were high. This is interesting, both in terms of the findings of Carello et al. (1989) and Plumert (1995). Carello et al. (1989) noted that adults tended to overestimate their performance on this task and Plumert (1995) found that, although both groups tended to overestimate their ability, 6-year-old children overestimated more than 8-year-old children. Could there be a developmental trend towards smaller overestimates and more accurate performance? In order to establish this, the performance of the two younger age groups must be examined.

In terms of signed differences between predicted and actual reach, the scores of the groups were significantly different only at the lowest surface height (20cm). This is also the surface where the shortest actual reaches were recorded. So although the 14+15 year old children overestimated slightly at this surface, the overestimates of children in both the 10+11 age group and the 12+13 age group were more than double the size of the oldest children. Interestingly, however, there was no signficant difference between the scores for the 10+11 age group and the 12+13 age group. So, similar to the findings of Plumert (1995), it seems that the younger children tend to overestimate more than the older children. When the frequencies of over- and under-estimation for the younger groups were examined, it could be seen that the fewest accurate trials and the highest number of overestimates were recorded by children in the 12+13 year age group. Similarly, when the correlation between predicted and actual reach was examined, these were lowest for the 12+13 year old boys.

This suggests that, although there may be a developmental trend towards resulting in fewer overestimates, the age group most likely to be undergoing an adolescent growth spurt are overestimating their ability in a similar way to the 10+11 year old boys and, on some measures, perform worse than both older and younger boys.

Comparison of mistrials between age groups:

In fact, the performance lag of the 12+13 year old boys in predicting their reaching ability was mirrored by the pattern of mistrials observed. On examination of the mistrials, it was quite clear that the group most likely to lose balance while reaching was the 12+13 year old boys. Since this group were also most likely to overestimate their ability and least likely to make accurate predictions of their reach, it would appear that they are having difficulty in recognising the limits of their zone of muscular reversibility. An overestimate of ability with respect to a specific environmental layout, *when acted upon*, may result in a loss of balance as the vertical line drawn through the body's centre of mass moves outside the base of support. However, it also seems likely that the mistrials resulting from acting on an overestimation of ability provide the feedback which allows the recalibration process to take place. The fact that the group differences were most apparent at the lowest surface height, where the movement to be controlled is likely to be the most unfamiliar, provides further support for this idea.

In terms of a developmental trend, then, it would appear that the progression towards more conservative assessments of ability can be identified in the three age groups studied. However, the marked differences in the performance of the 14+15 year old boys suggest that some kind of transition occurs around the age of the adolescent growth spurt. In fact, this transition may well be linked to the growth spurt: once the period of rapid growth is past, the developmental imperative which may result in younger children overestimating in order to test and develop their abilities may cease.

However, the results also leave a question unanswered. One of the key problems for children undergoing a growth spurt appears to be the correct identification of the limits of their zone of muscular reversibility. To what extent is the performance of the children most likely to be undergoing a growth spurt influenced by the changes in height? Several interrelated processes are occuring almost simultaneously: changes in height and limb length and changes in muscle mass. These in turn affect the centre of mass and moments of inertia of the body and the limb segments. If children undergoing a growth spurt are unsure of limb lengths, they would be more likely to base their estimate on their previous height and thus underestimate. The 12+13 year old boys in this experiment overestimated. An overestimate may occur in this group because, although they are taller, their moments of inertia have increased, making it more difficult for them to maintain balance in a forward reach. A further experiment is needed to separate the effects of changes in moments of inertia and the overall changes in height. The experiment described in the next chapter is an attempt to examine this issue in more detail.

Chapter Three

Estimating vertical reaching height: When do you need the step ladder?

Humans of all ages are motivated to explore their environments and this motivation is useful both in terms of outward directed, voluntary movements but also in terms of an on-going process of calibration, which in turn tunes the voluntary movements. In order to move, we need a system which informs us about our surroundings and our position within those surroundings, as well as information about our own capabilities with respect to those surroundings. The previous experiment describes an investigation of the abilities of children of different ages to identify their capacity to perform a specific action, namely reaching surfaces of different heights. The present experiment is a continuing investigation of the factors which allow children (and adults) to plan and execute appropriate actions.

Reaching movements are of particular importance to humans. Although they are often investigated in terms of *obtaining* something, for example picking up a piece of food, reaches can also involve other actions. Tool use, for example, involves manipulating an object to act on the environment in a certain way. Moreover, reaching movements are most often examined in terms of a forward movement. In fact, most experimental investigations of reaching involve just this type of movement. This is the case, whether the investigation involves an assessment of the kinematics of a reaching movement (Marteniuk et al, 1987), the development of reaching (von Hofsten, 1979), the visual control of reaching movements (Jeannerod, 1986) or the reachability of objects (Carello et al, 1989). The previous experiment investigated this kind of movement. However, another common type of reach involves placing something on (or obtaining it from) a high surface: for example, getting a book from a library shelf or a packet of biscuits from a high cupboard. However although reaching upward and reaching outward are broadly comparable, there are certain key differences between these two kinds of movements which are likely to prove informative. The key differences between upward and outward reach will now be explored, starting with a discussion of the nature of an outward reach as examined in the previous experiment.

Reaching experiments have yielded invaluable information about how humans produce accurate and appropriate movements in varying situations. In particular, it has been possible to investigate many of the important aspects of reaching movements and we can now examine a reaching movement while taking into account a number of factors about the actor and their environment. An example would be a set of experiments by von Hofsten (1993). These provide evidence demonstrating that a forward reach involves a preliminary adjustment in axial muscle groups which control posture and balance (von Hofsten, 1993).

We can therefore conclude that actors planning a reaching movement plan that movement with respect to the likely perturbation it will cause to normal posture. However, some movements will perturb posture more than others and these movements will also affect the upright posture of some individuals more than others (depending on physical proportions).

A forward reaching movement which involves stretching the arm forwards and leaning moves the centre of gravity forward and possibly even outside the body. It is easiest to sustain stability in an upright posture when a vertical line drawn through an individual's centre of gravity passes through their base of support. The system will become more unstable the further this line moves away from the base of support (Dyson, 1977). This situation characterises the movements which children were required to make in the previous experiment, but does not characterise an upward reach to the same extent.

This suggests that a small child (or an adult), when reaching forward, must be taking into account not only the distance they intend to reach and the length of their reaching limb, but also the position of their centre of gravity and to what extent its position will be altered by the reaching movement. The previous experiment tested this ability to the limit and found that, although individuals should be able to recognize the point at which a forward reach results in instability, this is not the case, with 12+13 year old children finding this more difficult than older and younger children. This finding suggests that it may be interesting to examine the performance of these groups of children on an equivalent reaching task, but where the movement of the children's centre of gravity is controlled. In other words, are children undergoing an adolescent growth spurt likely to be clumsy because they are unable to predict the consequences for their centre of gravity when making forward reaching movements, rather than because they cannot accurately judge the length of their growing limbs?

It is difficult to address this question looking at the results of the forward reaching task. However, forward reaching is only part of the reaching repertoire available to humans - we have sufficient degrees of freedom at our shoulder to be able to attempt reaches behind and in front of us, as well as above and below us. Anyone who has surveyed a library shelf and then gone to look for a small stool to increase their reaching height has made a decision based on the relationship between their physical dimensions and the environmental layout containing their goal object. In fact, it is only when the shelf is very close to the limit of our reach that we will actually try out the movement. However, this movement does not involve moving the centre of gravity outside the body - in fact the centre of gravity moves up slightly if the arm is held above the head. To some extent, this posture can actually increase the ability of the individual to respond to changes affecting balance, allowing more time to make corrections before stability is adversely affected, (Dyson, 1977).

What would be the predictions of the outcome of an experiment encouraging individuals to judge what height they could reach? Carello et al. (1989) demonstrated that individuals tend to overestimate their abilities in the forward reaching task. This was also observed in the previous experiment, where all thechildren tended to overestimate their abiities. However, in particular on the lowest surface, this overestimate was most likely to be observed in the 12+13 year old group, with 14+15 year old children equally divided between the more conservative underestimate or accurate response (50%) and overestimate (50%). Overestimation in a forward reach is the risky option and the consequences of overestimation may be error, failure to perform the movement successfully or a loss of balance. Overestimation in an upward reaching task simply involves failure to achieve the aim of the movement (placing the object on the shelf) and is unlikely to result in a fall.

In the case of the present experiment, it was considered that removing the component of the experiment which forced participants to allow their centre of gravity to move forward outside their bodies would improve the ability of the 12+13 year old group to predict the boundaries of their reach, leaving only a linear developmental improvement across the increasing age groups. This would provide additional evidence in support of the argument that it is the ability to predict the gravitational consequences of movement which is the main difficulty of the boys undergoing rapid growth.

The upward reaching task satisfies these requirements and a similar task has been carried out with young children (aged 6 and 8). Plumert (1995) observed that 6-year-old children were most likely to overestimate their abilities on this kind of task, followed by 8-year-olds, with adults still overestimating but less than the children. The present experiment is intended to develop the observations of the forward reaching task reported in the previous chapter, using an upward reach task similar to that employed by Plumert (1995). Additionally, it provides the opportunity to examine the degree of overestimation in children older than those who participated in Plumert's (1995) experiment to see if the trend for decreasing overestimation with increasing age is present between the ages of ten and fifteen.

The same three age groups as experiment one (using some of the same children and some new children) were studied in a task which involved making judgements about the height of shelf on which they could place a small object. Again, only boys were studied, this taking into account the fact that the adolescent growth spurt is most easily observed in boys while also controlling for any differences in impulsivity between boys and girls. The 12+13 year old group were again considered to be most likely to be in the rapid growth stage (Marshall & Tanner, 1986), with the younger and older groups studied for comparision purposes.

The upward reach can also be examined in another way which would not have been possible for experiment one. Warren (1984) proposed that actors should be able to perceive the boundary dividing possible from impossible movements, based on their biomechanical limitations. He suggested that dimensionless π-numbers could be obtained by scaling observers' maximum upward step by their leg length. The obtained number should be constant across all observers despite differences in leg length. He found a close fit between this π-number and the prediction of the observers about their maximum step scaled by leg length. This type of analysis is possible in an experimental setup where height and arm length are the key factors in the height a participant can reach. It is possible to derive an anthropometric reaching height for each participant by adding height to shoulder and arm length. Dividing actual reach by this should produce the same number for all participants and this would provide additional evidence that all the children are sensitive to the same environmental property.

Two predictions were made with respect to the present experiment. The first was that differences would be observed between the three age groups studied, but that it would be possible to explain these differences in terms of developmental progression and differences in height between the three groups. Related to this, when reach is scaled by anthropometric reaching height, differences between groups should disappear. Second, since the upward reaching movement is less likely to involve the same degree of instability as a forward reach, all children should overestimate more than they underestimate, but where a recent growth spurt has taken place children's overestimates should be reduced.

Method:

Participants:

67 participants were recruited from Primary and Secondary Schools in the Glasgow City Council Education Department area. Once each head teacher had agreed that the study could take place, a contact teacher identified a number of boys who would meet the criteria specified. These were as follows:

Boys eligible to take part had to be aged greater than 10 years and less than 12 years (Primary Schools) at date of testing, or less than 16 years (Secondary Schools) at date of testing. Teachers were informed that the aim was to obtain roughly equal numbers of boys in each of three age bands: 10/11, 12/13 and 14/15. It was explained that the aim was to study boys likely to be before, during and after the adolescent growth spurt. Teachers were asked to base their selection on the boys' age (not their size), but this proved difficult as not all teachers had easy access to this information, so in the case of the Secondary schools, boys were chosen in equal numbers from the first four years. Children with known and diagnosed coordination or movement difficulties were excluded from the sample.

Parental consent was obtained for the boys identified as suitable by the contact teacher. Table 3.1 summarizes the boys who took part in this experiment.

Table 3.1: Participant details.

Age Group	Mean Age in years and months	Age Range (yrs/ mths)	Mean Height	sd	range
Age 10+11, n = 21	10 years, 11 months	10/1 - 11/7	146.1cm	6.1	133.5-157.5cm
Age 12+13, n = 16	13 years, 3 months	12/4 - 13/11	153cm	10.5	131 - 172 cm
Age 14+15, n = 30	15 years.	14/2 - 15/10	171.3cm	7.5	153 - 186 cm

Materials:

The materials consisted of a shelf (20cm x 30cm) mounted on a shelf bracket which could be attached at different heights to a shelving strip held by the experimenter. In each location where testing took place, a position where it could be determined that the shelf bracket was always held vertical was selected. This was usually a room corner. A small cylindrical piece of wood, diameter 4cm, served as the target object which participants were asked to place on the shelf. The experimenter held a score sheet with details of the participant's name, date of birth and height. The shelving strip was coded for two groups of subjects - those above 1metre 55cm and those below 1metre 55cm and the height measurement on the score sheet determined which set of heights the experimenter used. This division was based on examination of the reaching height (height to shoulder plus arm length from acromium to tip of thumb) of a pilot group.

The score sheet was marked with a set of coded letters corresponding to the marks on the back of the shelving strip (which were not visible to participants). These coded letters were nine shelf heights, presented three times to each participant in randomised order. The heights were calculated to contain at least 2 unreachable heights for all participants and at least 2 easily reachable heights for each participant. This was possible by using two overlapping height sets. The two height sets were as follows:

A (boys under 155cm): 149.5cm, 156cm, 162cm, 168.5cm, 175cm, 181cm, 187.5cm, 194cm, 200.5cm.

B (boys 155cm and over): 194cm, 200.5cm, 206.5cm, 213cm, 219cm, 225.5cm, 232cm, 238.5cm, 244.5cm.

Procedure:

Participants were initially told that they would be taking part in two experiments designed to test balance and their judgements of height. Half of all participants completed the present experiment first and half completed another experiment first and the present experiment second. Participants were asked to approach the apparatus and wait until the experimenter explained the rules of the test to them. The experimenter gave each participant the following instructions:

"This is a kind of guessing game. Before you begin, I'll tell you a few things about it. I'm going to move this shelf up and down. The aim is for you to tell me at which heights you could put this object on the shelf. There are a couple of rules you should remember when you're guessing. You won't be allowed to jump, but you can stand on tiptoes. You must place the object on the shelf, not throw it. Any questions about these rules?

Before you try reaching, I want you to tell me which of the shelves you think you can reach. I'll show you the shelf at different heights twenty-seven times *altogether and each time you should say yes if you think you can put this on top and no if you think it's too high. It's important that you don't try it out until I ask you to at the very end. Have you any questions about that or would you like to start?*

Here's the first height. Do you think you could put it on this shelf?

Following the instructions, the experimenter presented three blocks of trials of the nine shelf heights, each block with the nine shelf heights presented in randomised order. The participant's response was marked down against each height.

Although instructed to answer yes or no, some participants responded by saying that they were unsure - this was marked as a "Don't Know". During coding, "Don't Know" was coded as no, since the participant had not given an affirmative response.

When the participant had responded to each of the 27 presentations, the experimenter handed them the target object. The first shelf height presented was the lowest shelf height the participant had previously said they could not reach. The shelf was then moved up or down to determine the highest shelf that the participant could reach and the experimenter noted this height.

Results:

The results of the present experiment are presented under a number of sub-headings. First, the mean maximum reach of the children in each of the three groups will be described, followed by an examination of the ratio of anthropometric reaching height to maximum reach. The next section will examine the children's predictions of their maximum reach. Following this, the relationship between predictions and maximum reach will be examined in terms of the diifferences between predictions and actual reach and in terms of the nature of the predictions (i.e. whether they were under or overestimates).

Measures of Maximum Reach:

Starting with the actual reaching height of children in the three groups, Table 3.2 gives the means and standard deviations. Children in the 14+15 age group were able to place the target object on higher shelves than either of the other two groups and children in the 12+13 age group reached higher shelves than did the children in the 10+11 age group. The reaches of children in the 12+13 age group were most variable, with a standard deviation of 15.91. This is likely to reflect the fact that the overall height of children in this group showed most variation (table 3.1). A one-way ANOVA compared the maximum reaching height for each of the three age groups. The differences in maximum height reached were significantly different ($F(2,64)=58.52$, $p<.001$) and a Bonferroni test (with significance level set at .05) showed that the maximum reach of the 10+11 age group was significantly different from the 14+15 age group. In turn, the maximum reach of the 12+13 age group was significantly different from that of the 14+15 age group. However, there were no significant differences between the maximum reach of the 10+11 age group and the 12+13 age group.

Table 3.2: Mean reach height in centimetres for each of the three age groups, 10+11, 12+13 and 14+15. Reach height is the highest shelf height successfully attained by each child.

	Mean	**sd**
Age 10+11	189.3	8.62
Age 12+13	197.9	15.91
Age 14+15	222.6	10.13

It was possible to examine the relationship between each child's highest reach and their anthropometric reaching height. The anthropometric reaching height was derived by measuring each child's height to the shoulder and adding their arm length from acromium to tip of thumb When examined separately, the Pearson correlation coefficient for the relationship between maximum reach and anthropometric reaching height for the 10+11 age group was $r=0.847$, ($p<0.0001$ (2 tailed)). For the 12+13 age group the correlation was $r=0.965$, ($p<0.0001$ (2 tailed)) and for the 14+15 age group, $r=0.948$, ($p<0.0001$ (2 tailed)). These high correlations suggest that each age group was reaching quite close to their maximum reach.

The lack of difference between the maximum reach of the 10+11 year old children and the 12+13 year old children was considered to be due to the fact that the mean height of children in these groups was not very different. To investigate this possibility, a One-way ANOVA was carried out on the effective anthropometric reaching height of children in the three groups (obtained by adding arm length to height to shoulder). This was significant ($F(2,64)=55.68$, $p < 0.0001$) but Bonferroni tests with significant level set to .05 showed that the 10+11 age group (mean 180.9, sd 8.9) did not have a significantly greater reaching height than the 12+13 age group (mean 188.9, sd 15.3). However, the 14+15 age group (mean 213.2, sd 10.4) had an anthropometric reaching height greater than both the 10+11 age group and the 12+13 age group.

Predictions of maximum reach:

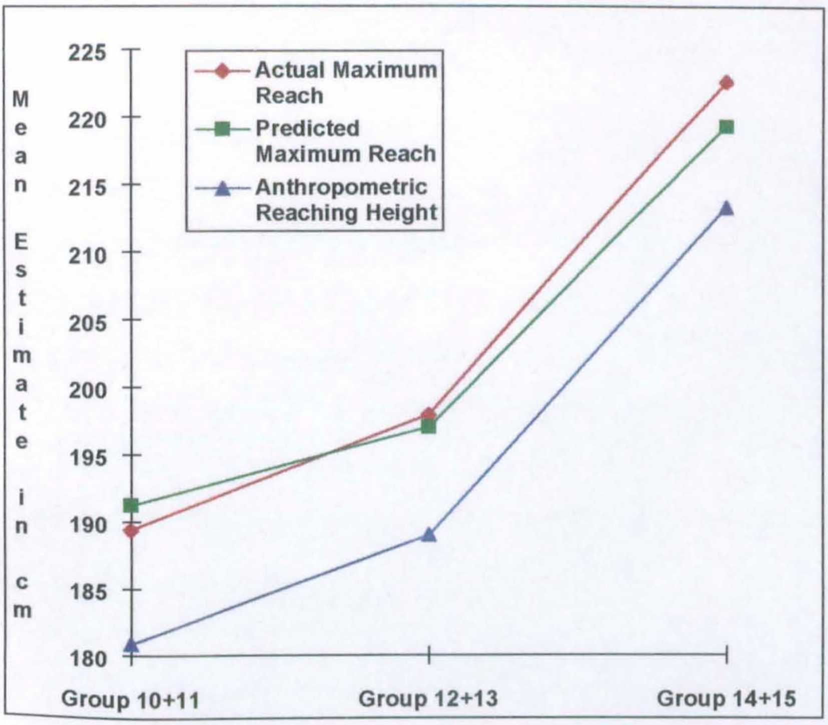
Children were asked to predict which were the highest shelves that they could reach. Table 3.3 below gives means and standard deviations for the children's predictions of their maximum reach, divided by age group.

Table 3.3: Mean maximum predicted reach, based on the highest shelf on which each child predicted they could place the target object (heights are in centimetres).

	Mean	**sd**
Group 10+11	191.21	8.01
Group 12+13	196.97	17.14
Group 14+15	219.23	11.05

Again, the increase in maximum height reached between the three groups reflects the fact that the mean height in each group increases. This is illustrated in Figure 3.4. The differences in maximum predicted reach between each age group were examined using a One-way ANOVA and were found to be significant differences ($F(2,64)=38.48$, $p<0.0001$. A Bonferroni test with significance level set at .05 showed that the significant differences were between the 14+15 group and the 10+11 group and between the 14+15 group and the 12+13 group. Again, the 10+11 group were not significantly different from the 12+13 group in terms of maximum predicted reach.

Figure 3.4: Comparision of the mean maximum actual reach made by children in each age group with their maximum predicted reach and with the anthropometric reaching height.



Relationship between maximum reach and predicted reach:

It was of particular interest to study the differences between the highest shelf the children reached (maximum reach) and their predictions. This difference gives an indication of how accurate the children were when they predicted which shelves they could or could not reach and also indicates whether they were over- or under-estimating. There were no significant differences between the groups on the absolute mean number of centimetres between actual and predicted reaches ($F(2,64)=1.45$, n.s.). When the direction is taken into account, some differences between the groups appear: the 10+11 age group overestimated their abilities slightly (mean 1.83cm; sd 6.43) whereas the other two groups tended to underestimate. In the case of the 12+13 age group, this underestimate was very small (mean -0.94cm; sd 7.68) whereas for the 14+15 age group it was rather larger (mean -3.37; sd

8.28). However, when examined using a One-way ANOVA, these group differences did not quite reach significance at the 5% level ($F(2,64)=2.90$, $p<0.0625$) and Bonferroni tests (with significance level set at .05) showed that differences between individual age groups were not significant.

Anthropometric reaching height, as described above, allows a calculation of π-numbers for this experiment. Participants' anthropometric maximum reach was calculated using measurements of height to shoulder plus arm length. Using the process described by Warren (1984), maximum actual reach was divided by anthropometric reaching height for each individual and group means were obtained. These were then compared with scaled predicted reach - where maximum predicted reach was divided by anthropometric reaching height. The means and standard deviations are displayed in Table 3.5 below.

Table 3.5: Mean π-numbers (maximum reach scaled by anthropometric reaching height) compared with mean scaled predicted maximum reach for each age group.

	π-number	sd	Scaled Prediction	sd
10+11 age group	1.048	0.027	1.058	0.041
12+13 age group	1.042	0.022	1.043	0.039
14+15 age group	1.045	0.016	1.030	0.038

A one-way ANOVA comparing mean π-numbers for each age group showed that the small differences between groups were not significant differences ($F(2,64)=0.149$, p=n.s.). However, a one-way ANOVA comparing the mean scaled predicted reach for each group was significant ($F(2,64)=3.396$, p<0.04). A Bonferroni test with significance level of .05 showed that the score for the 10+11 year olds was significantly different from that of the 14+15 year olds, but that the score for the 12+13 year olds was not significantly different from either group.

Having examined the mean differences between children's predictions and their maximum reach, the frequency of occurrence of over and underestimates in each group was then examined.

These data are set out in table 3.6 below. Because it was possible to consider the categories as ordinal (in terms of increasing age and in terms of an increasing error scale (minus through zero to plus)), in this case it was decided to examine these data using a Kendall's Tau-b Correlation. This showed that there was a significant negative correlation (k = -2.815, p<0.01): as age group increased, overestimates decreased and in addition, accurate responses were considerably more likely to occur in the youngest age group. A Chi-square carried out to examine whether there was a significant relationship between group membership and nature of estimate was only significant at the 10% level ($\chi^2 = 8.03$, $p < 0.09$).

Table 3.6: Degree of accuracy for participants in each group, described in terms of percentage of participants in each group who, respectively, underestimate, overestimate or are accurate (where predicted reach=actual reach).

	Underestimate	**Accurate**	**Overestimate**
Group 10+11	19%	38%	43%
Group 12+13	44%	19%	37%
Group 14+15	57%	23%	20%

DISCUSSION

In order to investigate the findings of the experiment described in Chapter 2 in more detail, it was decided to carry out a comparable experiment involving children's judgements of their maximum reach, but this time involving only upward movements. An upward reach was considered broadly comparable to the forward reach, with the key difference that, during the movement, a vertical line drawn through the centre of gravity during the movement would still pass through the base of support. A number of predictions were made with respect to this experiment. First, that differences would be observed between the three age groups studied, but that it would be possible to explain these differences in terms of developmental progression and differences in height between the three groups. In fact, it was predicted that, when each individual's reach was divided by their anthropometric reaching height, differences between groups should no longer be present. The second prediction took into account the likelihood that the upward reach would not challenge the child's control of balance as much as a forward reach, so all children should overestimate more than they underestimate. However, if a recent growth spurt had taken place children's overestimates should be reduced. These predictions will now be discussed in terms of group differences in actual and predicted reach and group differences between predicted and actual reach.

An examination of maximum (actual) reach in this experiment showed that the children's ability to reach differed between the three age groups. The maximum shelf height attained by children in each of the three groups increased as their age increased, but the differences in maximum reach between the two younger age groups (10+11 and 12+13) were not significant. Since one of the primary foci of this investigation is the change in height during early adolescence, this is worthy of more detailed discussion. A strong correlation between reaching height (height to the shoulder plus arm length) and maximum shelf height reached showed that there was a clear relationship between a child's height and the maximum reach they managed. Because of this, it was decided to examine the differences between anthropometric reaching height of children in the three groups and this showed that the lack of differences in maximum reach between children in the 10+11 age group and children in the 12+13 age group was very likely because there was no significant differences between their anthropometric reaching height.

However, anthropometric reaching height was, in all cases, rather lower than actual maximum reach. It is likely that any difference between anthropometric reaching height and maximum height reached can be attributed to two factors. First, children's reaching height did not allow for the fact that they could stand on tiptoes and that the shoulder can be raised slightly in this kind of action. Second, maximum reach was measured in terms of the highest shelf attained and there was a 6.5cm difference between each shelf height. If a child was capable of reaching, say, 168.5cm, but not 175cm, they may also have been able to reach 170cm. However the data suggests that children were trying quite hard to attain their maximum reach. This was still the case when the correlation between reaching height and maximum reach was examined for each age group in turn.

The children's predictions also increased as age group increased. However, the difference between the predictions of the youngest and middle age groups (10+11 and 12+13 respectively) were not significant ones. This mirrored the fact that there were no significant differences between the anthropometric reaching height of these children.

So far, the results for maximum actual reach and predicted reach mirror the anthropometric data closely and appear to provide support for the idea that group differences can be accounted for in terms of height differences.

However, when maximum actual reach is subtracted from predicted reach, a slightly different pattern emerges. Some children were more likely to overestimate than others. Although these differences between groups did not quite reach significance at the 5% level, there was a noticeable trend apparent. This was examined in more detail by looking at the frequency of occurrence of over and underestimates. Similar to observations by Plumert (1995) and Plumert & Schwebel (1997) in children up to 9 years of age, the 10+11 year old group in this experiment were significantly more likely to overestimate their ability to reach the shelves than the older children. However, most interestingly, the youngest (10+11 year old) children also produced most accurate responses. Underestimates were more common among both 12+13 year old children and 14+15 year old children and both of these groups were less likely to produce accurate responses.

Additionally, comparison of the frequency of over- and under-estimates (table 3.6) with the frequency data presented in Table 2.9 in the previous chapter shows that there is a similar pattern: frequency of underestimates increases with age, while frequency of overestimates decreases.

This trend is rather unexpected, since at face value, the present experiment involves a judgement of a less complex action than the experiment described in Chapter Two. How might this be explained? Plumert (1995) has observed overestimates decreasing with age in children younger than the participants in the present experiment. However, Carello et al. (1989) and Rochat & Wraga (1997) have observed that overestimates are common among adults. The 12+13 year old children and the 14+15 year old children in the present experiment are underestimating noticeably in a task which involves a relatively pure judgement of reaching height. Given that varying degrees of overestimation are the norm, a possible explanation for the underestimation seen in these groups is that some children in both groups have recently undergone a growth spurt and as a result are actually basing their estimates on their previous height. The only way to examine this in more detail is to relate height change to performance on the test more directly, by tracking height change over a period of time. This is, in fact, the approach taken in Chapters Seven, Eight and Nine.

The results of the present experiment, taken together with the outcome of the previous experiment, suggest that there is a developmental trend whereby children gradually make more conservative judgements with age. It would seem that this transition occurs around the age of 12 or 13 - the time most likely to coincide with the adolescent growth spurt. This must be associated with a gradual process of calibration, a dynamic process whereby the individual's physical dimensions are matched with environmental affordances and constraints in successive trials. It would appear that the ongoing calibration of movement and the development of a more adult pattern of movement planning is most likely to be perturbed when the movement involves a degree of difficulty and especially when that difficulty involves movements where the individual's centre of gravity is low or moves forward outside the body. Hence it could be suggested that the ongoing calibration is likely initially to affect an individual's judgement of the length of limb segments and their position and that this calibration is a process which is constant throughout growth.

However, the present results also suggest that only at a later stage is there a recalibration of the effect of the change in length and weight of body segments on the individual's centre of gravity and consequently an improved performance on tasks involving extreme perturbations of the position of an individual's centre of gravity.

This would suggest that adolescents undergoing a growth spurt would be most likely to appear clumsy in actions where a vertical line through their centre of gravity does not pass through the base of support. This would include sports such as tennis, the beginning of a sprint or even in everyday actions such as picking up a bag or picking up or putting down a cup or glass. The experiments described in Chapters Four and Five investigate adolescents' control of movement and balance in locomotor activities, since these involve quite fine control of posture and balance.

Chapter Four

Estimating locomotor gap clearance: stepping over puddles.

Experiments one and two investigated the abilities of rapidly growing adolescents to reach for objects in a variety of situations. However, one of the most common comments about "clumsy teenagers" is that they "trip over their own feet". Upright locomotion is a skill which we begin to develop later in infancy than reaching for objects, but once mastered, children use this skill constantly, exploring their ability to run, jump, skip and balance while upright. It is also apparent that children and adults have the ability to tailor this skill to different environments - watching children play hopscotch in the schoolyard shows the ability children have to place their foot in exactly the right place, in the same way that they can perform an accurate goal directed reach. The present experiment is intended to explore the relationship between the growth changes experienced in early adolescence and the child's ability to observe a situation involving locomotor skills and produce an action appropriate to that situation.

An early ecological study of humans judging the affordances which surfaces offer for locomotion is also a developmental study. Walk and Gibson (1961) showed that six month infants would not cross a transparent surface covering an apparent drop. More recently, Warren (1984) allowed adults to make judgements about the climbability of different stair riser heights and showed that their judgements were based on body scaled information. In terms of goal-directedness, Lee, Lishman and Thomson (1982) showed that long-jumpers were able to alter step length during their run-up in order to hit the take off board accurately. Once the skill of locomotion is learned, we can use our knowledge of our own abilities and body characteristics to judge exactly what movements are necessary to achieve a goal.

In order to examine children's predictions of their locomotor ability, a possible approach would be an experiment where they are asked to make a judgement about a stepping task. The judgement could then be compared with the children's actual performance in a similar way to the previous experiments. A suitable paradigm which would involve such a comparison probably follows from Gibson's (1971) suggestion that animals may detect "a gap between the cliff-edges which (depending on its width) may afford jumping". Studies based on this suggestion appear in the literature in a number of forms. For example, Jiang, Mark, Anderson & Duncan (1993) asked observers to judge the crossability of a gap from different distances from the edge of the gap and Plumert (1995) and Plumert & Schwebel (1997) asked children to judge whether they could step across gaps that were just within, just beyond and well beyond their ability.

This type of experiment is quite comparable to the previous experiment. Participants are still asked to make an assessment of their action capability with respect to a specific environmental layout. Unlike experiment one, however, participants do not lean so far forward that a vertical line through their centre of gravity does not pass through their base of support. Additionally, this is a type of assessment which is often made - can I step across the puddle without stepping into it, or should I walk around? Judgements in such a task would depend on a number of factors, including leg length, fitness, speed of approach and size and depth of gap. The rate of growth of the leg in adolescent children during the growth spurt usually peaks first, followed over the course of a few months by body breadth and about a year later by trunk length (Schroeder, 1992). The likelihood of misjudgements involving step length may, in part, be explained by these rapid changes.

The present experiment requires children in the same three age groups studied in experiment one and two to make estimates of the size of step they are capable of performing in a given situation - in this case, the situation is a large step or jump from a standing start onto a target object. The estimates will be made by stopping the moving target at the position considered to be just within stepping distance.

The predictions with respect to this experiment are that, once leg length is taken into account, there should be no difference between the performance of children in the three groups in terms of actual step length. However, based on the results of the two previous experiments, childrens predictions about their maximum step length should differ between groups. The increasingly conservative judgements of older children should be observed in this experiment also. However, in the light of the results of experiment one, children in the 12+13 year age group should be more likely to consider risky movements to be safe.

Method:

Participants:

101 participants were recruited from Primary and Secondary Schools in the Glasgow City Council Education Department area. Once each head teacher had agreed that the study could take place, a contact teacher identified a number of boys who would meet the criteria specified. These were as follows:

Boys eligible to take part had to be aged greater than 10 years of age and less than 12 years of age (Primary Schools) at date of testing, or less than 16 years of age (Secondary Schools) at date of testing. Teachers were informed that the aim was to obtain roughly equal numbers of boys in each of three age bands: 10/11, 12/13 and 14/15. It was explained that the aim was to study boys likely to be before, during and after the adolescent growth spurt. Teachers were asked to base their selection on the boys' age (not their size), but this proved difficult as not all teachers had easy access to this information, so in the case of the Secondary schools, boys were chosen in equal numbers from the first four years. Children with known and diagnosed coordination or movement difficulties were excluded from the sample.

Parental consent was obtained for the boys identified as suitable by the contact teacher. Table 4.1 summarizes the boys who took part in this experiment.

Table 4.1: Participant details.

Age Group	Mean Age in years and months	Age Range	Mean Leg Length	sd	range
Age 10+11, n = 38	11 years, 1 month	10/0 - 11/11	89.4 cm	4.8	80 - 100cm
Age 12+13, n = 34	13 years	12/0 - 13/11	95.1 cm	5.3	85 - 109cm
Age 14+15, n = 29	14 years, 11 months	14/0 - 16/6	104.2 cm	8.0	88 - 117cm

Materials:

Materials consisted of a red and yellow circular target (diameter 30cm) attached to a 1 metre long wooden handle, white tape, a video camera with tripod and a score sheet indicating the order of trials for each subject. Rooms where testing took place were allocated by the school on the basis of availability and the experimenter explained that the room needed to be at least 4 metres in length and wide enough to allow placement of the video camera so that the full 2.5 metre testing space appeared on the film.

On arrival in each school, a measuring tape set to 2.5 metres was placed on the floor and the tripod mounted video camera was set up at right angles to the tape, 2.5 metres away. Where necessary, the tape position was then adjusted until its full length appeared in the viewfinder of the video camera. At this point the experimenter marked the position of the left and right start lines (the end of the tape measure and the 2.5 metre point of the tape measure respectively) using white masking tape on the floor and the centre of each start line (where it was crossed by the tape measure) was marked in black. The position of the video camera tripod was also marked with tape. The measuring tape was then removed leaving a left and right start line 2.5 metres apart.

Procedure:

Participants were initially told that they would be taking part in two experiments designed to test their judgements of reach and step length. Half of all participants completed the present experiment first and half completed another experiment first and the present experiment second. Participants were asked to approach the start line and wait until the experimenter explained the rules of the test to them. The experimenter gave each participant the following instructions:

"This is a test of how far you think you can jump without a run-up. Imagine that you have to jump over a puddle to avoid getting your feet wet - how big a puddle would you chance jumping over without a run-up? I will be moving a target towards and away from you while you stand behind this line. To begin with, I don't want you to jump. All you need to do is tell me where to stop the target.

Stand behind this line please. I will move the target towards(away) from you. Tell me where to stop the target when it is just close enough to jump onto(just before it goes too far to jump onto), getting your whole foot on the target. I'll move the target until you're sure it's in the right place. Any questions about that?"

Once the instructions had been given, the experimenter started the trials. Each participant gave four estimates. Two estimates were when the target was moving towards them and two were when the target was moving away from them. Additionally, on two trials they stood at the right start line to make their estimates and on two trials they stood at the left start line to make their estimates. The order of trials was counterbalanced across all the participants. Before the participant started, the experimenter started the video camera and held up a card with the participant's number written on it. After each estimate made by the participant, the experimenter held up a card with the trial number written on it.

As the experimenter invited the participant to move from the left to the right start line and vice versa, they led the participant around the setup, to avoid giving them the opportunity to try out any large steps or jumps. Once all four estimates were made, the participant was asked to jump four times, twice from the left and twice from the right. The experimenter reminded them that this was to be a large step or a standing jump and that they couldn't run up to the start line. These jumps were also recorded using the video camera.

Data Preparation:

The video recordings of the participants were analysed to produce estimates and actual steps in centimetres in the following way. A video player was attached to a high resolution monitor and a XY position analyser. This allowed cross hairs to be displayed over the video image. For each school, the initial picture of the setup including the two start lines and the measuring tape was displayed. The cross hairs were placed at the end of the tape measure on the left hand start line and this point was set to 000. The cross hairs were then moved across the screen until they rested on the end of the tape measure at the start line on the right hand side of the screen. The XY position analyser displayed the number of TV scan lines covered between these two points and this was noted and taken to be equivalent to 2.5 metres.

This process gave a metric value to each scan line and this was used to calculate both size of estimate and size of actual step for each participant. A test using a calibration object displayed at the start of each video showed this data transcription system to be accurate to approximately 2cm. Separate calibration was performed for each transcription session.

Results:

The data resulting are described below under a number of headings. In the first instance, the step length of the children in each of the three groups was examined. In order to examine step length with differences due to leg length eliminated, maximum step for each child was divided by leg length. Additional information is provided by examining the statitical differences between mean leg length for children in each of the three groups. Following the discussion of step length, predicted step length will be examined in a similar fashion. Differences between maximum step and prediction are also examined, followed by the frequency of over and underestimate.

Step length:

Using the video analysis procedure described above, the actual maximum step size for children in each of the three age groups was obtained. Step length is a function of leg length, but it is of most interest to examine the relationship between predicted and actual step length irrespective of leg length. For this reason the analyses described below are carried out on data which has been scaled by leg length. This was done by dividing maximum step length (out of four trials) for each individual by their leg length, thus eliminating any variation in performance due to leg length. Mean maximum step (both scaled and before scaling) are shown in Table 4.2.

First, the unscaled mean maximum step length was examined. A One-way ANOVA comparing the means for maximum step for the three age groups showed that the differences between the means were significant ($F(2,98) = 3.75$, $p < 0.027$. However, once maximum step was scaled by leg length, this significant difference disappeared and a One-way ANOVA comparing the maximum step length scaled by leg length for each of the three age groups showed that there were no significant differences between groups ($F(2,98)=1.3361$, n.s.). This demonstrates that, once leg length is taken into account, children in each of the groups were performing at a similar level. Non-significant differences between mean maximum step for the three groups (seen in Table 4.2) may be due to factors such as the different levels of physical activity between children in the different age groups.

Table 4.2: Maximum step length scaled by leg length for three age groups, 10+11, 12+13 and 14+15. Before scaling, maximum step length (shown with sd in the rightmost column) was expressed in centimetres.

	Scaled Mean Step Length	**sd**	**Actual Mean Step Length**	**sd**
Age 10+11	1.70	0.26	153cm	25 cm
Age 12+13	1.78	0.29	169cm	31 cm
Age 14+15	1.65	0.36	171cm	36 cm

Leg Length:

The difference between mean maximum step length for children in the three groups was a significant one, but was there a significant difference in leg length? In order to confirm this, a One-way ANOVA was performed which showed that differences in leg length between the three age groups were signficiant ($F(2,98) = 45.18$, $p < 0.0001$). Bonferroni tests with significance level set at .05 showed that each group was significantly different from the other two groups. Mean (and sd) leg length for children in each group is shown in Table 4.1 above).

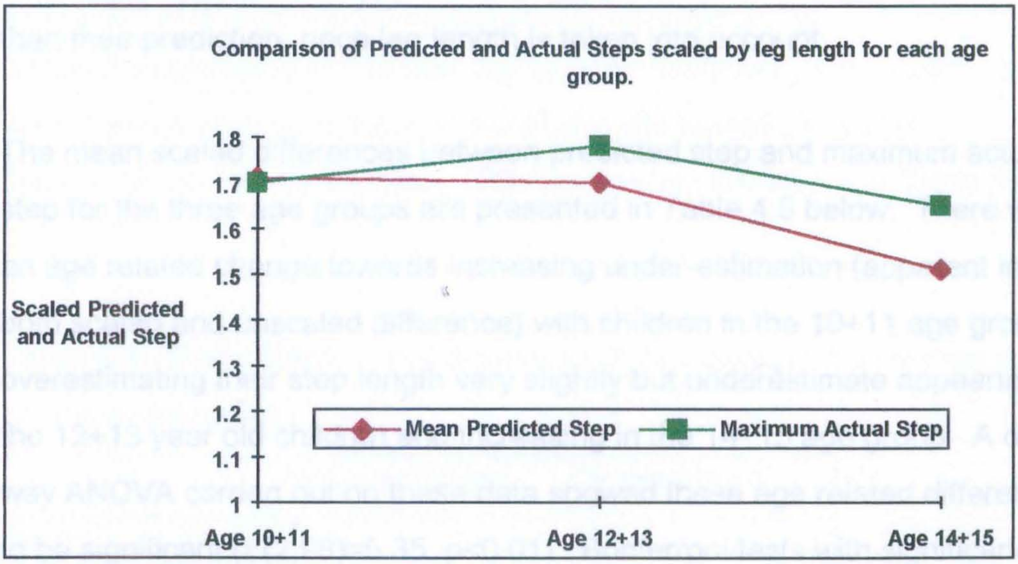
Step predictions:

Children were asked to predict what their maximum step would be by stopping a target moving which was moving towards (for two trials) or away (for two trials) from them. A mean prediction was obtained from the four trials. The mean predictions are seen in Table 4.3 (in brackets) and in this case, it can be seen that the group which predicted the largest step was the 12+13 year old children. However, differences between the means for the three groups were examined using a One-way ANOVA and were not significant ($F(2,98) = 0.92$, n.s.). Again, it was decided to eliminate any variations in predictions which might be due to leg length, so the mean predicted step length was divided by leg length to produce a scaled figure for each child. The mean scaled prediction for each group can be seen in Table 4.3 below. Once leg length had been eliminated, it could be seen that the predictions of the 14+15 age group were relatively small for their leg length and that those of the 12+13 and 10+12 age group were very similiar to one another when the factor of leg length had been removed. A one-way ANOVA examined these differences between the groups and found them to be significant ($F(2,98)=5.39$, $p<0.01$). Bonferroni tests, with significance set at .05, examined the differences between the groups, finding that there was no significant difference between the predictions of the 12+13 and 10+11 age groups, but that both groups were significantly different from the 14+15 age group.

Table 4.3: Mean predicted step length scaled by leg length for three age groups. Original predicted step length is shown in brackets.

	Mean	sd
Age 10+11	1.71 (154 cm)	0.27 (23.6)
Age 12+13	1.70 (162 cm)	0.26 (24.2)
Age 14+15	1.51 (157 cm)	0.27 (25.6)

Figure 4.4: Comparison of mean maximum step length with mean predicted step length between the three participating age groups. Data have been scaled to remove the variable of leg length.



In addition, Figure 4.4 below compares predicted step length with actual maximum step length (both scaled for leg length). This shows that the nature of the differences between groups when actual and predicted step are compared varies across groups and this cannot be attributed to differences in leg length. Figure 4.4 also shows that the direction of the difference, i.e.

overestimation or underestimation, differs between the groups. This is examined in more detail below.

Difference between mean maximum step and mean predicted step:

In the previous experiments, measures of difference between predictions and actual performance have been an interesting way of distinguishing between the age groups. In this case, the differences between each child's maximum step length and their mean predicted step length was examined. Each of these measures was divided by leg length to remove this variable. This results in a measure of how accurate the children were in their predictions and additionally, whether their performance was better or worse than their prediction, once leg length is taken into account.

The mean scaled differences between predicted step and maximum actual step for the three age groups are presented in Table 4.5 below. There was an age related change towards increasing under-estimation (apparent in both scaled and unscaled difference) with children in the 10+11 age group overestimating their step length very slightly but underestimate appearing in the 12+13 year old children and increasing in the 14+15 age group. A one-way ANOVA carried out on these data showed these age related differences to be significant ($F(2,98)=5.35$, $p<0.01$). Bonferroni tests with significance set at .05 showed that the difference scores for the 10+11 and 12+13 age group's scores were significantly different from the scores of the 14+15 year old group but that 10+11 and 12+13 age groups were not significantly different from one another.

Table 4.5: Mean signed difference between predictions and actual step by leg length for children in each of the three age groups. Difference scores were obtained by subtracting mean actual step from mean predicted step. (Again, unscaled differences are shown in brackets).

	Mean	**sd**
Age 10+11	+0.01 (+0.87cm)	0.18 (16.53)
Age 12+13	-0.08 (-7.64cm)	0.19 (17.57)
Age 14+15	-0.14 (-13.97cm)	0.23 (22.59)

Nature of estimates:

In addition to the difference measures described above, frequency of over and under estimates can be examined for each age group. There were no accurate judgements in this task and to allow analysis by Chi-square, any values which were quite close to zero were still scored as over or underestimates as appropriate. The frequencies are shown in Table 4.6.

Table 4.6: Percentage of children in each age group who overestimated or underestimated.

	Underestimate	**Overestimate**
10+11	45%	55%
12+13	56%	44%
14+15	82%	18%

Percentages of overestimates decreased with age and percentage of underestimates increased with age as observed in the previous experiments.

It was possible to analyse this data using a Chi-square test and this showed that the distribution of scores was significant (χ^2 =8.92, $p<0.01$) A Kendall's tau-b correlation was also carried out and this showed that the linear trend observed in these data was a significant one (k= -3.12, $p<0.003$): as age group increased, frequency of overestimates decreased, whereas as age group increased, frequency of underestimates increased.

Discussion

The present experiment examined the type of predictions that children of different ages made about their step length. This differed from the previously described experiments in two ways. First, it involved making an assessment of a movement which is involved in locomotion, but which can be tailored to specific circumstances and environments in exactly the same way as are the movements described in the reaching experiments (Lee, Lishman & Thomson, 1982). Second, children participating in this experiment were not placed in a situation which required them to explore the limitations placed on their movements by moving their centre of gravity forward outside their body, as was the case in the first experiment.

The findings of the present experiment are, however, consistent with those described in the previous chapters. Children were encouraged to try to produce the longest step they could on a number of occasions and a mean step length was obtained. The previous experiments and the work of other researchers has established that children's performance will differ in line with their differing height (Carello et al., 1989; Warren, 1984), so variation due to height differences was eliminated by dividing children's mean step length by their leg length. The results indicated that this scaling process effectively eliminated the differences which existed between the children in the different age groups with respect to maximum step length - all children were performing at a comparable level.

However, when the predicted step length for children in each of the age groups was scaled in a similar way, a series of differences in predictions was observed between them. Younger children (10+11 and 12+13) tended to believe that they could step considerably further than could children in the 14+15 age group, when leg length had been taken into account. When signed differences between predictions and maximum step were examined, it could be seen that the youngest children's predictions were slight overestimations of their ability, but the predictions of both the 12+13 and the 14+15 year old children were underestimates. Similar to the trend observed in experiment two, as the children get older the relationship between their predictions and their actual performance changes, with the frequency of overestimates gradually decreasing. In fact, in this case, the difference measures show a developmental trend, with 10+11 year old children overestimating very slightly, the 12+13 year old children underestimating their step length and the 14+15 year old children underestimating most.

The key to interpreting these data is the lack of significant differences between groups on scaled maximum step compared to the group differences on scaled predictions. Both older groups (the 12+13 age group who are most likely to be in the course of a growth spurt and the 14+15 age groups who are likely to have recently undergone a growth spurt) tend to predict smaller steps than they perform. The youngest children overestimate their ability very slightly. It would appear that the children in the older groups are less able to use their knowledge of their physical characteristics to predict step length and this is most likely due to a time lag in reconciling new physical dimensions with ability to perform a specific task. The fact that the greatest underestimate is present in the 14+15 year old group may reflect a more general trend away from overestimating in combination with the fact that these children may have recently undergone accelerated growth.

An examination of the findings of Plumert (1995) and Plumert & Schwebel (1997) where younger children performed a similar task can help interpret the present experiment. Although not directly comparable to the method used in the present experiment, their procedure involved children aged 6 and 8 and adults making judgements of their abilities. No breakdown of tasks is included, but a task very similar to the present one is included with three others (two of which are comparable to the experiments described in chapters two and three). An examination of the data presented in Plumert (1995) indicates that between 20 and 35% of adult's judgements were overestimates, whereas between 40 and 60% of the children's judgements were overestimates. The method used in the Plumert (1995) study does not provide information as to the breakdown of accurate and underestimated responses. When these results are compared to the frequency of over and underestimate described above, it can be seen that the degree of overestimation seen in the 10+11 year old children and the 12+13 year old children is within the range described by Plumert (1995) for the 6 and 8-year old children, but that the performance of the 14+15 year old children showed overestimates even lower than those recorded by Plumert (1995) for adults.

Although the data reported by Plumert (1995) includes the results of four experiments including judgement of step length, the nature of their results in combination with the findings of the present experiment provide further support for the idea that a combination of a trend away from large overestimates and a poorly recalibrated knowledge of stride length is likely to result in underestimation. The mean signed difference scores indicate that this trend is present in both the 12+13 and 14+15 year old children and that overestimates produced by the 10+11 year old children were likely to be quite small. In this case, the growth spurt and post growth spurt children are performing quite differently from both Plumert's (1995) 6- and 8-year olds but also quite differently from the adults.

Furthermore, the results of the present experiment are in line with those described in chapter three. Older children are more likely to underestimate their ability to reach up to high shelves, whereas younger children less likely to underestimate and more likely to overestimate. This contrasts with the results of the experiment described in chapter two, where both 10+11 and 12+13 year old children overestimate quite noticeably. The relationship between overestimates and the high number of mistrials for the 12+13 year old children in that experiment leads to the proposal that growth spurt and post growth spurt children are most likely to underestimate when the task requires a well-calibrated knowledge of limb length, but are more likely to overestimate when the task requires a well-calibrated knowledge of limb length and changes in moments of inertia. The results of the experiment described in chapter two suggest that this latter calibration may be complete in the 14+15 year old children, but still ongoing in the 12+13 year old children. The relationship between this recalibration and very recently experienced rapid growth will be examined in more detail in the experiments described in chapters six, seven and eight.

However, the effects of rapid growth on balance in a locomotor task, rather than in a reaching task as in chapter two, will be examined in more detail in the next chapter.

Chapter Five

Speed/accuracy trade-off in a simple locomotor task: walking the plank.

Locomotor skill increases with age and it is likely that the affordance of locomotion of different surfaces will change in line with a developing child's locomotor skills and physical development. For example, certain surfaces afford support for human locomotion and this affordance is something which humans can detect from an early age (Gibson, Riccio, Schmuckler, Stoffregen, Rosenberg & Taormina, 1987). A particular instance of this is the increasing enjoyment children apparently derive from walking along walls and other narrow raised surfaces, to the extent that they will engage in these activities for their own sake. However the results of the forward reaching experiment described in Chapter Two would suggest that, during the adolescent growth spurt, children (in this case boys) may have difficulty in identifying situations where balance can safely be maintained during an action.

This suggests that boys around the age of the growth spurt may have more difficulty than older or younger children in maintaining balance during a difficult locomotor task, since they are more inclined to attempt actions which are beyond their current ability. As previously discussed, balance is easiest to maintain in situations where there is a broad base of support and where a vertical line drawn through the individual's centre of gravity passes through their base of support. This is easily illustrated by the relative difficulty of maintaining balance while standing with feet in line (one in front of the other) compared to standing with feet apart. With feet in line, the arms immediately come up to maintain equilibrium and increase stability. Locomotion becomes increasingly difficult as the size of the base of support is reduced: in this case an example would be moving from standard walking to walking heel to toe (and thus narrowing the base of support) which increases the likelihood of losing balance.

An observation of poor performance on a precision-walking task in children during the adolescent growth spurt would suggest that, overall, these children have difficulty in maintaining balance while controlling a broad range of goal-directed movements. The results of the forward reaching task described in Chapter Two (experiment one) indicated that 12+13 year old boys (those most likely to be experiencing a growth spurt) were more likely to lose balance (as measured by mistrials) than were older or younger boys. However the forward reaching task involves a very specific action, whereas a task which required children to maintain balance while walking on increasingly narrow bases of support could highlight any general problems with coordinating balance which may be associated with an adolescent growth spurt.

The transition from standing to walking has been described as having the "appearance of falling and regaining one's balance by stepping forward"(Wollacott & Jensen, 1996, p. 375). These authors describe the body's response to changes in the position of the centre of mass involved in locomotion. Forward locomotion involves moving the centre of mass forward of the ankle joint - a movement which would disturb static balance. Such a movement or shift of the centre of mass needs a forward step to maintain balance. It is exactly such a balance event which was studied in experiment one, with the condition that the children had to identify the point at which their centre of mass was so far forward that they needed to step forward to regain static balance. Since the identification of this point seemed, in experiment one, to pose a particular problem for children during the growth spurt, a difficult locomotor task should also tap into any balance problems in this age group. It would be of particular interest to identify any problem in this age group, since it is generally considered that locomotor activity has assumed an adult pattern in even the youngest children in the present study: "the evolution of the locomotor act involves nearly the whole of childhood and extends almost to the beginning of puberty" (Bernstein, 1967, p86). This author considered an adult pattern of locomotion to have been established by age 10.

In fact, despite Bernstein's assertion, there is some evidence that suggests that an examination of adolescents' ability to maintain balance is worthy of examination. Rarick (1982) describes an experiment using a stadiometer - a platform where the subject places one foot on either side of a pivoting fulcrum and then attempts to maintain the platform in equilibrium. The experiment described by Rarick (1982) examined the performance of blind and sighted children on this task. It would appear that a developmental conflict between visual and kinesthetic recalibration may occur, since Rarick (1982) reported that, in adolescents (aged twelve to fourteen), performance did not improve so rapidly with practice in sighted children as it did in blind children and that, additionally, although performing at a better level than younger children, sighted adolescents improved less with practice whereas blind adolescents improved as much as children in the younger group.

This suggests that a balance task would be an interesting approach to the study of adolescent changes. Balance tasks and precision walking tasks have been used to determine the role of vision and practice on performance (Robertson, Collins, Elliott & Starkes, 1994 and Proteau, Tremblay & DeJaeger, 1998) and the role of visual proprioception in the development of balance control in children (Williams, McClenaghan, Ward, Carter, Brown, Byde, Johnson and Lasalle, 1986). In the present experimental paradigm, however, the children are not given a chance to practice the task, since it could be hypothesised that practice is exactly what is needed to eliminate any differences in control of balance between children at the growth spurt stage and older or younger children.

As a result, an experiment which requires children to maintain balance while performing the relatively unfamiliar activity of walking on different width beams was designed. Additionally, to make the task more difficult and increase the likelihood of errors occurring, children were asked to perform the task as quickly as possible, but without falling off the beam. Any difficulties which rapidly growing adolescents might experience should be highlighted by such an approach. Additionally, this task provided an opportunity to observe children actually making decisions about their abilities while in action, rather than asking them to make verbal judgements before the event. Each child had to decide how fast they could traverse the beam without falling off, a decision based on beam size and their knowledge of their own ability.

The following predictions were made. First, all children should find it increasingly difficult to traverse beams as the beams become smaller in width. A floor level "beam" - a tape fixed to the floor was also included as a control. Second, if the control of dynamic balance during locomotion is affected by the changes associated with the adolescent growth spurt, rapidly growing children should produce more errors, resulting in a slower overall performance on the beams and in more recorded mistrials (stepping off the beam).

Method:

Participants:

84 participants were recruited from Primary and Secondary Schools in the Glasgow City Council Education Department area. Once each head teacher had agreed that the study could take place, a contact teacher identified a number of boys who would meet the criteria specified. These were as follows:

Boys eligible to take part had to be aged greater than 10 years of age and less than 12 years of age (Primary Schools) at date of testing, or less than 16 years of age (Secondary Schools) at date of testing. Teachers were informed that the aim was to obtain roughly equal numbers of boys in each of three age bands: 10/11, 12/13 and 14/15. It was explained that the aim was to study boys likely to be before, during and after the adolescent growth spurt. Teachers were asked to base their selection on the boys' age (not their size), but this proved difficult as not all teachers had easy access to this information, so in the case of the Secondary schools, boys were chosen in equal numbers from the first four years. Children with known and diagnosed coordination or movement difficulties were excluded from the sample.

Parental consent was obtained for the boys identified as suitable by the contact teacher. Table 5.1 summarizes the boys who took part in this experiment. Each child who took part in the experiment was measured during the testing session. A measurement of each child's overall height in centimetres was obtained using a measuring stick and this was followed by measurement of leg length, which was measured from floor to head of pelvis of the right leg (determined by asking each child to put their finger on their "hip bone"). This was verified by the experimenter and the child held the end of the tape on the head of the pelvis while the experimenter extended the tape to the floor.

Table 5.1: Participant details.

Age Group	Mean Age (years and months)	Age Range	Mean Leg Length	sd	range
Age 10+11, n = 22	11 years.	10 years, 1 month - 11 years, 7 months.	88.5 cm	5.7	79cm - 103cm
Age 12+13, n = 24	13 years, 3 months	12 years, 4 months - 13 years, 11 months.	96.0 cm	8.5	71cm - 108cm
Age 14+15, n = 38	15 years.	14 years, 2 months - 15 years, 10 months.	104.4 cm	5.0	95cm- 115cm

Materials:

Materials consisted three 2 metre long lengths of wood, 30mm high, each with a bracket fixed to the underside at each end to prevent it turning over when stepped on. The beams were 37mm, 50mm and 67mm in width respectively. Beams were lined up side by side, with 50cm in between each. 50cm from the narrowest beam, a tape 50mm wide and 2 metres long was fixed to the floor.

The experimenter held a score sheet with the order of the beams for each child, plus a stopwatch. The score sheet had space for a time for each trial as well as number of errors (stepping off the beam).

Procedure:

Participants were initially told that they would be taking part in two experiments designed to test their judgements of reaching height and balance. Half of all participants completed the present experiment first and half completed another experiment first and the present experiment second. Participants were asked to approach the first beam and wait until the experimenter explained the rules of the test to them. The experimenter gave each participant the following instructions:

"The aim of this test is for you to walk along these beams, heel to toe, as fast as you can without falling off. I'll be timing you with this stopwatch and if you fall off, I'll stop the stopwatch while you go back to the beginning and start again. This means that if you fall off, your time will be longer. You get three tries on each beam in case you get faster with practice. I'll tell you which order to walk along the beams the first time and then you keep walking them in that order until the end. Have you any questions about that? OK, let's start - remember to walk heel to toe. I'll ask you if you're ready and then say "GO".

After the experimenter had given the instructions, the trials took place (three on each of the planks and three on the floor level tape), with the experimenter noting the times, the number of errors and reminding the participant, where necessary, to walk heel to toe.

Results:

The data resulting from the present experiment were examined in a number of different ways. First, mean time to complete the beams was examined for children in each of the three age groups. Following this, maximum time to complete the beams and minimum time to complete the beams were examined. Finally, number of mistrials for the 37mm beam and Total Number of Mistrials were examined for each of the three age groups. These will be dealt with in turn below.

Mean time to complete the beams:

Mean time of the three trials on each of the four beams (floor level, 37mm beam, 50mm beam and 67mm beam) was obtained for the three age groups. These means and standard deviations are shown in Table 5.2.

Table 5.2: Mean time in seconds (standard deviations in brackets) to complete each beam for children in each of the three age groups.

	37mm Beam	**50 mm Beam**	**67mm Beam**	**Floor Level**
Age 10+11	6.15 (2.65)	5.28 (2.16)	5.06 (1.58)	4.93(1.62)
Age 12+13	7.39 (3.05)	5.93 (1.94)	5.21 (1.36)	5.33 (1.41)
Age 14+15	7.54 (3.94)	5.68 (2.17)	4.98 (1.76)	5.00 (1.46)

These means indicate that the 10+11 year old boys' performance improved as the width of beam increased and that they recorded their best performance on the floor level beam. The results for the older children was similar, in that their performance improved as beam width increased, but both 12+13 year old children and 14+15 year old children found the floor level beam more difficult than the widest beam.

When differences between the age groups are examined, the 12+13 year old age group recorded the slowest times on all beams with the exception of the narrowest beam (37mm), where the 14+15 year old boys were slowest.

A Two Factor ANOVA of Mixed Design with factors of Beam (Floor, 37mm Beam, 50mm Beam and 67mm Beam) and Age (10+11 age group, 12+13 age group and 14+15 age group) was carried out. This showed that there was a significant main effect of Beam ($F(3,243)=32.32$, $p<0.0001$, but no significant main effect of Age ($F(2,81)=0.63$, n.s.) and no significant interaction.

These results indicate that all children perform differently depending on the width and height of the beam, but that there are no significant differences between age groups, despite the fact that examination of the means indicates a trend for the 12+13 age group to perform less well than the other two groups on three out of four beam categories.

Minimum and Maximum time to complete beams:

When a child stepped off the beam during a trial, the stopwatch was paused until the child resumed from the beginning. This meant that the mean time to complete the beam typically included one or more quite long trial. Because of this, it was decided to examine the minimum, or best time for each child on each beam since this was the trial during which mistrials were least likely to have occurred. Similarly, the maximum, or worst time for each child on each beam was examined, since this was the trial where mistrials were most likely to have occurred. Mean values (with standard deviations in brackets) are shown for children in each group, with Minimum group times shown in Table 5.3 and Maximum group times shown in Table 5.4.

Table 5.3: Mean Minimum (best) time to complete each beam for children in the three age groups. Standard deviations are shown in brackets and all times shown are in seconds.

	37mm Beam	50mm Beam	67mm Beam	Floor Level
Age 10+11	4.66 (1.68)	4.42 (1.67)	4.15 (1.25)	4.32 (1.57)
Age 12+13	5.29 (1.49)	4.75 (1.27)	4.58 (1.28)	4.85 (1.35)
Age 14+15	4.92 (1.67)	4.70 (1.59)	4.35 (1.35)	4.49 (1.33)

Again, as beam width increased, the mean minimum time to complete decreased. With respect to floor level, the 10+11 year old children and the 14+15 year old children found the 67mm Beam easier to complete than floor level and the 12+13 year old children found both the 50mm Beam and the 67mm Beam easier to complete than floor level.

In this case, the 12+13 year old children had the slowest minimum time of all three groups on all four beam conditions, with the 10+11 year old group recording the fastest overall times on all beams.

A Two Factor ANOVA of Mixed Design with Beam (Floor, 37mm Beam, 50mm Beam and 67mm Beam) as one factor and Age (Age 10+11, Age 12+13 and Age 14+15) as the second factor was carried out. There was a significant main effect of Beam ($F(3,243)=12.84$, $p<0.0001$) but no main effect of Age ($F(2,81)=0.71$, n.s.) and no significant interaction between Beam and Age.

Thus, when the minimum time to complete the beams was examined, the difference between the performance of the 12+13 year old group was always the slowest performance, regardless of which beam was examined and the

10+11 year old group always completed fastest. Again, this trend was not significant when between-subject scores were examined.

Maximum time to complete the beams was also examined: these were the trials on each beam width most likely to be affected by number of errors. Means are shown in Table 5.4.

Table 5.4: Mean Maximum (worst) time to complete each beam for children in the three age groups. Standard deviations are shown in brackets and all times shown are in seconds.

	37mm Beam	50mm Beam	67mm Beam	Floor Level
Age 10+11	7.97 (4.21)	6.21 (2.86)	5.96 (1.86)	5.52 (1.75)
Age 12+13	10.05 (5.67)	7.55 (3.48)	5.87 (1.57)	5.85 (1.56)
Age 14+15	11.51 (9.63)	6.90 (3.61)	5.71 (2.60)	5.53 (1.62)

In this case the mean times for the 37mm Beam are noticeably worse than for the other Beams - reflecting the fact that errors are most likely to occur on the narrowest beam (error data are described below). In this case, the 12+13 year old group only performed worst on Floor Level and the 50mm Beam, with the 14+15 year old group performing worst on the 37mm Beam and the 10+11 year old group performing best on Floor Level, the 37mm and 50mm Beams, but worst on the 67mm Beam.

A Two Factor ANOVA of Mixed Design with Beam (Floor, 37mm Beam, 50mm Beam and 67mm Beam) as one factor and Age (Age 10+11, Age 12+13 and Age 14+15) as the second factor was carried out. There was a significant main effect of Beam ($F(3,243)=24.03$, $p<0.0001$) but no main effect of Age (F(2,81)=0.81, n.s.) and no significant interaction between Beam and Age.

Mistrials:

The number of mistrials for each group was also compared. Table 5.5 shows both mean Total Mistrials for each group and mean mistrials on the narrowest beam (37mm), (where mistrials predominantly occurred) for each group.

Table 5.5: Mean Total Mistrials for each age group and Mean Mistrials on the 37mm Beam for each age group. (Standard deviations are shown in brackets).

	Mean Total Mistrials	**Mean Mistrials 37mm Beam**
Age 10+11	0.27 (0.46)	0.14 (0.35)
Age 12+13	0.63 (0.92)	0.50 (0.72)
Age 14+15	0.79 (1.21)	0.66 (1.02)

In each case, the oldest children were most likely to record mistrials and the youngest were least likely to record mistrials. A one way ANOVA showed that the difference between groups on Mean Total Mistrials (F(2,81)=1.93, n.s.) was not a significant difference. However, examination of the difference between the groups on Mean Mistrials for the 37mm Beam (F(2,81)=2.90, $p < 0.06$) was significant at the 10% level and Bonferroni tests (with significance level set at .05) showed that the mean number of mistrials for the 10+11 year old boys was significantly less than the mean number of mistrials for the 14+15 year old boys.

Discussion:

The first prediction that was examined in the present experiment was that all children should find it increasingly difficult to maintain balance during beam walking as beam size decreased. The second prediction was that, if the dynamic control of balance is affected by changes related to the adolescent growth spurt, the 12+13 year old children should find the task more difficult that children in the other two age groups and that this difficulty should be reflected in poorer performance on the task.

Data were examined under three key headings in the previous section and a brief discussion of these headings will be followed by a general discussion of the findings of this experiment.

Mean time to complete beams:

As predicted, mean time to complete a beam increased as beam size decreased for all children. There was very little difference between mean performance on floor level compared with the 67mm beam. Children did find traversing the narrowest beam (37mm) much more difficult than any of the other beams. However, there were no significant differences between the performance of children in the three age groups, although examination of the mean times indicates that overall, 10+11 age group always performed better than the older children and that children in the 12+13 age group tended to be slowest. It is interesting that the differences between groups were not significant ones, since there were clear differences between the age groups in terms of mean leg length.

Minimum and Maximum time to complete beams:

These were examined in order to highlight the difference between times when errors were unlikely to have been made (fast times because the child did not fall off the beam and have to restart) and times where errors were most likely to have occurred (trials where children were most likely to have fallen off the beam and had to restart). However, the results were similar to those discussed above. There were significant improvements in performance as beam size increased, but although the 10+11 continued to perform best, followed by the 14+15 year old children and the 12+13 year old children, these time differences were not significant ones.

Mistrials:

The task instructions encouraged children to make a judgement of the maximum speed they could complete the task without falling off a beam and the expectation was that children likely to be undergoing a growth spurt (12+13 age group) would be most likely to misjudge this maximum speed and consequently have the most mistrials. However this was not the case: children in the 14+15 year old age group were most likely to fall off the beam during a trial and the 10+11 age group were least likely to fall off and the only significant difference was between the mean number of mistrials for the oldest and youngest children.

Overall, these results are unexpected, though there are a number of possible explanations for the pattern observed in the present experiment. In the first instance, it was predicted that, if children during the adolescent growth spurt were more likely to have problems with maintaining balance while controlling ongoing movement, then they would perform less well than children in the other groups and with more mistrials. The fact that there were no significant differences between groups may indicate that these children do not have any problem with this type of dynamic balance control - and confirm Bernstein's (1967) assertion that after age 10, an adult pattern of locomotor control is present. However, in situations where these children have to judge a *critical point* where the safest strategy would be to switch to a qualitatively different movement, as in experiment one, they may have difficulty.

Although the differences between groups were not significant, the 12+13 year old children tended to perform worst of all groups, regardless of whether maximum speed, minimum speed or average speed was examined. This slow performance also tended to occur on all beam widths. However, the largest number of mistrials was recorded in the 14+15 year old group - significantly more than in the 10+11 year old group, though not significantly more than in the 12+13 year old group. An interpretation of this could be that the 12+13 year old children were aware that, on this task, they might have difficulty in maintaining balance so they slowed their performance accordingly. This might also account for the lower number of mistrials.

Bearing in mind the lack of significant performance differences between the age groups, the final explanation offered for this pattern of results was that a balance beam test was of equal difficulty for all children. Leading from this conclusion would be the suggestion that the problem in identifying regions of reversibility of movement which the 12+13 year old children experienced in the forward reaching experiment (described in Chapter Two) did not occur here - there was no region of reversibility to identify. Perhaps children during the growth spurt need to learn about the changes in length and centre of mass of individual limb segments in *specific* tasks because there is a lack of transfer between specific instances (Proteau, Tremblay & DeJaeger, 1998). Locomotion occurs all the time, but coordinating balance in a forward reaching task of the type studied in Chapter Two occurs only infrequently.

Chapter Six

Relationship between growth and performance I: Shove ha'penny revisited.

The four experiments described in the preceding chapters have examined developmental changes in perceptuo-motor control in late childhood and early adolescence. The findings of the experiments described in these chapters add to the current body of knowledge about developmental changes during early childhood and infancy, in that they demonstrate that children's ability to perform certain actions increases in line with their growth and that they become better able to use their increasing skill to plan and control their actions. Additionally, the results have indicated that children must keep their changing abilities in tune by an ongoing process of calibration. In line with the results of previous research (Plumert, 1995, Plumert & Schwebel, 1997, McKenzie et al., 1992), the findings of these experiments has shown that children tend to overestimate their abilities, but that the amount of overestimate decreases with age.

However, the preceding four experiments have also highlighted a developmental change which is not linear. In a number of respects and across several experiments, it has been observed that the performance of the 12+13 year old boys was less well tailored to the situation than was the performance of both younger and older boys. It has been highlighted that the age when the adolescent growth spurt is most likely to occur in boys is around the time of the child's thirteenth birthday (Marshall & Tanner, 1986). For the child, the growth which takes place during the year of peak height velocity is much greater than the amount of growth which took place in any one year during the previous eleven or twelve years of life.

One of the main themes of this research is to investigate the speed at which adolescents manage to recalibrate their movement to take account of this change and whether the speed of recalibration is the same for all actions. The findings of the previous four experiments have indicated that there may be a measurable period during which the adolescent has not yet fully adjusted to the unusual amount of growth which they have experienced and that this can be observed by asking them to judge what actions they can perform as well as analysing the appropriateness of the actions which they do perform.

However, at this point it can only be stated that there is a change in the performance of 12 and 13 year old boys relative to 10+11 year old boys and 14+15 year old boys. The cross-sectional approach used in experiments one to four can give no indication of whether any individual boy aged 12 or 13 has experienced or is in the course of a growth spurt, or indeed what proportion of boys in the 12+13 age group have experienced a growth spurt. Since the age of onset of the adolescent growth spurt varies in the population, differences in performance between the age groups examined could be attributed to cognitive or hormonal changes linked with adolescence. This problem also exists in, for example, the study of balance where a performance lag was identified in sighted as compared to blind adolescents (Rarick, 1982). In order to link performance differences more closely with growth, it is necessary to know the growth status of the participants in more detail.

Given the interesting performance of the 12+13 year old boys in the previous experiments and suggestive evidence of the effects of physical changes in adolescence (Jensen, 1981), the next three experiments will examine the relationship between height changes and performance in this age group. The aim of these experiments will be to determine whether any difference in performance on tasks such as those previously described in Chapters Two and Three can be linked more closely to changes in height, limb length and centres of mass of the body and limbs.

A group of boys aged 12 and 13 years of age were recruited from a different set of schools which in this case were six secondary schools in the Glasgow City Council area. On the experimenter's firist visit, the boys were measured. Six months later, on the experimenter's second visit to the school, the boys were measured again and performed the three tasks, the results of which are described in this chapter, Chapter Seven and Chapter Eight. Due to the nature of the tests used, it was decided only to test at the end of the six month period. This is because, in a paradigm that compares estimates with actual performance, the child realises that their estimates are not equivalent to their actual performance once they begin actual trials (Mark et al., 1990). This effect is quite marked and it was felt that it would be memorable enough to invalidate a second test, even following a six month interval.

The first experiment with this group of boys was a repeat of the experiment described in Chapter Two. This experiment was chosen because the results described in Chapter Two indicated that any performance lag observed in adolescents may be the result of ongoing recalibration of both height and of changes in centres of mass and muscle power. This particular experimental design, which effectively requires children to judge the relationship between their strength and their rotational moments of inertia in a forward reach, should highlight calibration differences between High Growth and Low Growth groups of children in terms of the effectiveness of their recalibration.

A number of predictions were made with respect to the present experiment. First, it was predicted that there should be an identifiable relationship between the height of the participants and their reaching ability. However, since the High Growth group will have recently experienced major growth, they should be less accurate in judging their reaching ability than children in the Low Growth Group.

Second, in line with the results of the experiment described in Chapter Two, there should be a closer relationship between the predictions and actual reaches of children in the Low Growth group.

Third, again following from the results of the 12+13 year old group in Chapter Two, overestimations in the High Growth group should be accompanied by an increase in the number of mistrials for this group. Children who are growing rapidly should find it more difficult to identify their region of muscular reversibility. Attempting reaches at the limit of their zone of muscular reversibilty should result in falls and loss of balance. This should not be case for the Low Growth group.

Method:

Participants:

118 participants were recruited from six Secondary Schools in the Glasgow City Council Education Department area. Once each head teacher had agreed that the study could take place, a contact teacher identified a number of boys who would meet the criteria specified. These were as follows:

Boys eligible to take part had to be aged 12 or 13 years of age (a small number of participants were aged 14 because of the time lag between the teacher making up a list of suitable participants and the test date). Teachers were informed that the aim was to obtain roughly equal numbers of boys aged 12 and aged 13. It was explained that the aim was to study boys likely to be in the course of the adolescent growth spurt. Teachers were asked to base their selection on the boys' age (not their size). Children with known and diagnosed coordination or movement difficulties were excluded from the sample.

Parental consent was obtained for the boys identified as suitable by the contact teacher. Once parental consent had been obtained, the researcher visited each school and measured each participant. Measurements were taken of total height, arm length from acromium to tip of thumb, leg length from foot to head of femur and foot length from heel to end of big toe. The child was informed that they were taking part in a study of the effects of growth and that the researcher would return in six months at which time they would be measured again and would take part in some short tests.

After a six month interval (timed to coincide with the school summer holidays since growth is greatest during summer months), the researcher returned to the school. Of the 118 children measured in the first phase of the study, 74 were seen on the second visit. Each child was measured in exactly the same way as during the first visit.

Each child's height at first visit was subtracted from their height at second visit, giving a measure of growth during the six month period. Children were then divided into high and low growth groups. The high growth group (n= 22) grew between 5 and 9 centimetres during the six months whereas children in the low growth group (n= 35) grew between zero and three centimetres. Seventeen children grew between 3 and 5 centimetres and these data were not included the the analyses.

Table 6.1: Participant details.

Group	**Mean Age (years and months)**	**Age Range**	**Mean Height, 1st visit**	**Mean Height, 2nd visit**
High Growth n = 22	13 years and 2 months (sd 8 months)	12 years, 6 months - 13 years, 10 months.	156.5 (sd11.8)	162.7 (sd11.6)
Low Growth n = 35	13 years and 2 months (sd 5 months)	12 years, 1 months - 14 years, 1 month.	157.4 (sd9.37)	159.1 (sd9.32)

Materials:

The test apparatus consisted of a set of 4 movable surfaces, which when fully extended measured 60cm in length and were 20, 40, 60 and 80cm above floor level respectively. Four sets of card, each marked with a different set of 20 randomised letters at 2cm intervals, up to a maximum distance of 40cm from the front of the surface were also used. These fitted in retaining pieces on the front of each surface height, ensuring that they were consistently located on top of the surface. Randomised letters were used to ensure that, since each participant saw a different set of letters on each surface height on each of four trials at each surface height, they would make an independent judgement of distance on each trial and not simply memorise and repeat the previous judgement.

A start line was taped to the floor 70cm away from the front of the fully extended surfaces and participants were requested to stay behind this start line at all times during the experiment. The target of the reach was a small cylindrical object 1cm in depth and 4cm in diameter.

Procedure:

Participants were initially told that they would be taking part in three experiments designed to test their judgements of height and distance. Order of participation was counterbalanced, with one third of participants completing this experiment first and the remainder completed either one or both of the other experiments first. Participants were asked to approach the start line and wait while the experimenter explained the rules of the test to them. The experimenter gave each participant the following instructions: *"This is a kind of guessing game. Before you begin, I'll tell you a few things about it. The aim is for you to put this object down as far away from you as possible on each of these boxes. There are a few rules about how you do this. You can't touch the floor with your hand or foot on the other side of this line while you're trying to place the object and you must be able to stand up again without losing your balance after you have put the object down. You must place the object down on one of these marks and not throw or push it. Any questions about these rules?*

Before you do any of that, I want you to tell me which mark you think you are going to be able to reach. I'll ask you four times at each of these four different heights - that's sixteen times altogether - but it's important that you *don't try out the moves until I ask you to at the end. Have you any questions about that or would you like to start?*

OK, here's the first level - the marks each have a letter name beside them. Look at the marks and tell me, using the letter name, which one is the farthest you could put this object down on."

The order of presentation of both surface height and set of randomised letters was counterbalanced. The experimenter marked down each of the participants' responses and extended or retracted the surfaces as appropriate, placing the letter card on top. After all the judgements had been made, the experimenter handed the target object to the participant and briefly reminded them that they should not cross the start line, or place their hand on either the floor or the surface to keep their balance. The participant then performed four actual reaches at each surface height (again order of presentation was counterbalanced) and the experimenter noted down which mark the target object was placed on. Additionally, all trials where subjects lost their balance and placed either their hand or foot over the start line were recorded as mistrials. When this occurred the experimenter invited the participant to try again at that surface height to make up the correct number of valid trials.

Results:

The results of the present experiment were examined in a number of different ways. The difference in height between the groups of children was examined in order to determine whether any differences between the groups in length of reach could be attributed to height differences. Actual reach was examined next, in the light of the description of group mean height. Following this, the mean predictions of children in the two growth groups was examined as was the relationship between actual performance and predictions. Finally, the mean number of mistrials for children in each group was examined.

Differences between groups:

Analyses of the characteristics of children in the High Growth group and the Low Growth group were carried out. Mean height and age for both groups are listed in Table 6.1 above. When the second measurement mean height for children in the High Growth group was compared with that of the Low Growth group, the differences between the means for the two groups were not significant (t= -1.23, n.s), although the mean height for the High Growth group was slightly greater and had a higher variance than the mean height of the Low Growth group.

Additionally, there were no significant differences between mean age in months of the High Growth group and the Low Growth group (t=0.12, n.s.), although the age range for the Low Growth group was slightly larger.

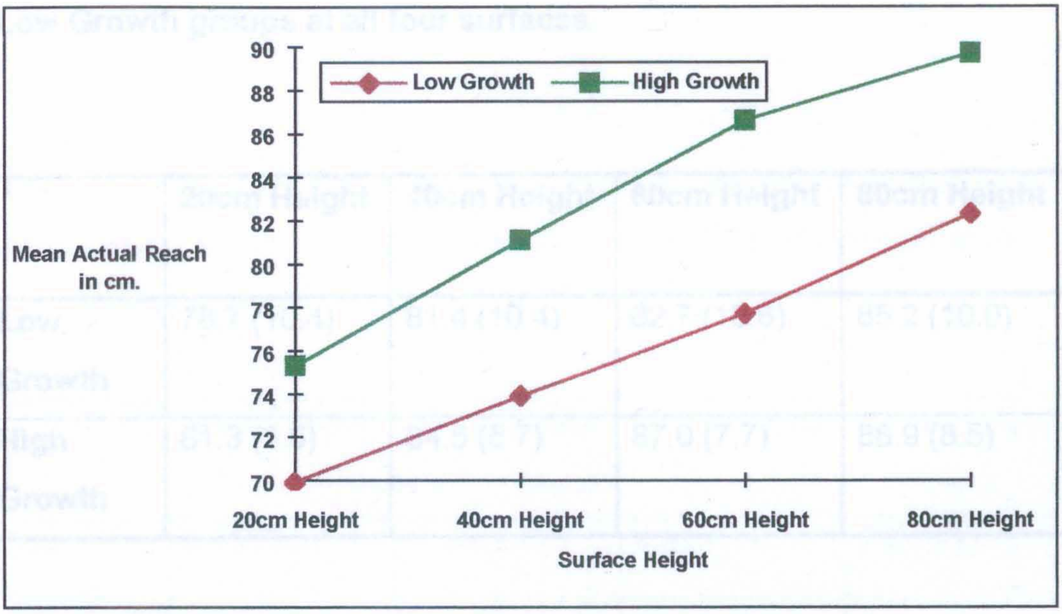
Measurements of actual reach:

There were performance differences between the High Growth and Low Growth groups in terms of the distance they reached and these means appear in Table 6.2. These means shows that the boys in the High Growth group reached further than did the children in the Low Growth group at all surface heights. A 2 x 4 Repeated Measures ANOVA with between-subjects factor of Growth (High Growth and Low Growth) and a within-subjects factor of Surface Height (20cm, 40cm, 60cm, 80cm) was carried out. This showed that there was a significant main effect of Growth ($F(1,55) = 15.79$, $p < 0.0001$), a significant main effect of Surface Height ($F(3,165) = 212.60$, $p < 0.0001$) and a significant Growth x Surface Height interaction ($F(3,165) = 3.19$, $p < 0.025$). This is illustrated in Figure 6.3. The main effect of Growth (High vs Low) is interesting, given that the differences between mean height of the High Growth and Low Growth groups were not significant ones. However, although not a significant difference, the High Growth group mean height was greater than that of the Low Growth group and the High Growth group outperformed the Low Growth group in terms of actual reach, so the direction of the differences are consistent with one another.

Table 6.2: Mean Actual Reach (and sd) for children in both High and Low Growth groups at all four surfaces.

	20cm Height	40cm Height	60cm Height	80cm Height
Low Growth	69.9 (5.6)	73.9 (5.9)	77.7 (7.1)	82.3 (7.1)
High Growth	75.3 (8.9)	81.1 (8.2)	86.6 (8.3)	89.7 (7.1)

Figure 6.3: Mean Actual Reach for both Low and High Growth groups at 20cm, 40cm, 60cm and 80cm Surface Heights.



Measurements of predicted reach:

The pattern of results for predicted reach is quite different. In this case, the predicted reach of the High Growth group was greater than the predicted reach of the boys in the Low Growth group. The means for predicted reach for each group can be seen in Table 6.4. However, a 2 x 4 Repeated Measures ANOVA with between-subjects factor of Growth (High Growth and Low Growth) and a within-subjects factor of Surface Height (20cm, 40cm, 60cm and 80cm) showed no significant difference between the High and Low Growth group in terms of predictions ($F(1,55) = 2.06$, n.s.), although, similar to the actual reaches, predicted reach increased with Surface Height

($F(3,165) = 39.05$, $p < 0.001$). There was no significant interaction between Growth and Surface Height.

Table 6.4: Mean Predicted Reach (and sd) for children in both High and Low Growth groups at all four surfaces.

	20cm Height	40cm Height	60cm Height	80cm Height
Low Growth	78.7 (10.4)	81.4 (10.4)	82.7 (10.6)	85.2 (10.0)
High Growth	81.3 (6.6)	84.5 (5.7)	87.0 (7.7)	88.9 (8.5)

Relationship between predictions and actual reaches:

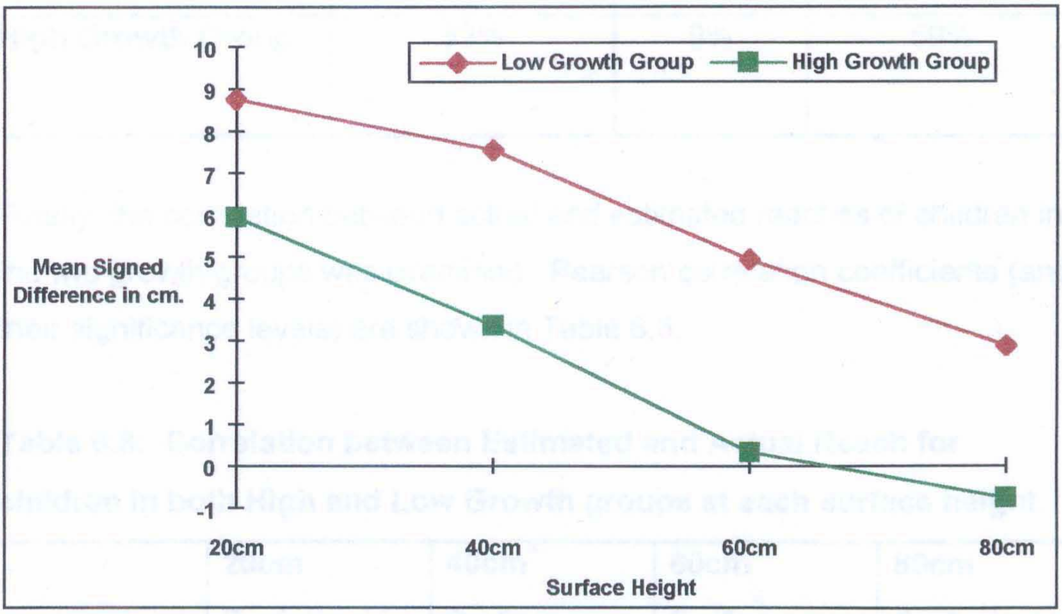
Given that there was a significant difference between the High and Low Growth groups in terms of actual reach, but not in terms of predictions, it is worthwhile to examine the relationship between the predictions and the actual reaches of the two groups in more detail. Signed difference between predicted and actual reach was examined first. For each child, the mean actual reach was subtracted from mean predicted reach and overall group means obtained. These signed difference means are shown in Table 6.5 and illustrated in Figure 6.6. This shows that the difference between predicted and actual reach for boys in the Low Growth group was a higher positive score at all surface heights than the means for the High Growth group. In fact, the difference between predictions and actual reach was a negative one on the higher surfaces for boys in the High Growth group. However, as in the previous version of this experiment, reported in Chapter Two, the difference between predicted and actual reach decreased as surface height increased and this was the case for both High and Low Growth groups.

Table 6.5: Mean Signed differences (with sd) between predicted and actual reach for children in both High and Low Growth groups at all four surface heights.

	20cm Height	40cm Height	60cm Height	80cm Height
Low Growth	8.75 (9.3)	7.54 (8.4)	4.92 (7.4)	2.9 (8.2)
High Growth	5.94 (11.1)	3.36 (8.8)	0.33 (8.7)	-0.77 (7.3)

A further 2 x 4 Repeated Measures ANOVA with a between-subjects factor of Growth (High Growth and Low Growth) and a within-subjects factor of Surface Height (20cm, 40cm, 60cm and 80cm) showed that the differences between High and Low Growth groups only approached significance ($F(1.55) = 3.29$, p , 0.075) although there was a significant main effect of surface height ($F(3,165) = 21.08$, p , 0.0001).

Figure 6.6: Mean signed difference between predicted and actual reach for both Low and High Growth groups at 20cm, 40cm, 60cm and 80cm surface heights.



The frequency of predictions in both the High and Low Growth groups which were either over or underestimates was examined (all surface heights included). The percentage of responses which were over or underestimates is shown in Table 6.7. However no category of accurate responses was included in the analysis on this occasion, as there was no difference between the two groups (9% accurate responses for both High and Low Growth groups). A Chi-square showed that there was a significant relationship between growth and nature of prediction (χ^2=3.87, p<0.049) when overestimates and underestimates were compared.

Table 6.7: Percentage of responses which were either over or under estimates for both High and Low Growth groups.

	Underestimates	Accurate	Overestimates
Low Growth Group	21%	9%	70%
High Growth Group	32%	9%	59%

Finally, the correlation between actual and estimated reaches of children in the two growth groups was examined. Pearson correlation coefficients (and their significance levels) are shown in Table 6.8.

Table 6.8: Correlation between Estimated and Actual Reach for children in both High and Low Growth groups at each surface height.

	20cm Surface	40cm Surface	60cm Surface	80cm Surface
Low Growth Group	0.46 ($p<0.005$)	0.59 ($p<0.0001$)	0.71 ($p<0.0001$)	0.58 ($p<0.0001$)
High Growth Group	0.00 (n.s.)	0.24 (n.s.)	0.40 ($p<0.06$)	0.58 ($p<0.005$)

There was a significant positive correlation between the estimated reach and the actual reach of children in the Low Growth group at all four surface heights. However, there was no significant correlation between the estimated reaches and the actual reaches of children in the High Growth group at the 20cm and 40cm surface heights and a noticeably lower correlation between estimated and actual reach at the 60cm surface height than in the Low Growth group. At the highest surface (80cm) the correlation between estimated and actual reach was 0.58 for both groups.

Mistrials:

The total number of mistrials during testing was examined. Mistrials were where children touched the floor or surface with their hand, or crossed the start line with their foot during a reach. The mean number of mistrials for the Low Growth group was 2.4 (sd 2.16) and the mean number of mistrials for the High Growth group was 2.59 (sd 2.40). These means were not significantly different ($t=0.30$, n.s.).

Discussion:

These data have been considered under a number of headings in the results section. Each of these will now be discussed in turn, followed by a commentary on what the overall implications are likely to be.

Age and height of children in each group:

The rationale for comparing the height and age of the two groups was to help determine whether these factors could contribute to any differences in performance between the two groups. With respect to height, there was no significant difference between the mean height of the two groups on the day they performed the test (second measurement). This suggests that actual overall height of the participants in the two groups would not determine performance on the task.

The children were allocated to High or Low Growth group on the basis of their *height change* over the six month period of the study. Children in the Low Growth group grew by between zero and three centimetres, while children in the High Growth group grew between five and nine centimetres. It is thus very likely that children in the High Growth group were undergoing a growth spurt. This is based on the fact that their age is compatible with the usual age of the adolescent growth spurt in boys and also based on the amount of growth in a six month period. Marshall & Tanner (1986) estimated that, in the year of the growth spurt, "the average is in the region of 9.5cm/year for boys" which is "nearly twice the velocity in either sex just before the adolescent growth spurt begins (about 5cm/year)" (Marshall & Tanner, 1986, p. 172). Since the children in this study were only tracked over a six month period, five to nine centimentres growth over six months is very likely to be evidence for a growth spurt in progress. Children in the Low Growth group could be either just before or just after a growth spurt. The possibility that some of them were just post-growth spurt is based on their age (with a slightly larger age range) and the fact that, at date of first measurement, the maximum height in this group was 176cm - quite tall for a pre-growth spurt child. Mean height at "take-off" is usually around 155cm. However, the standard deviation for the height of the Low Growth group is quite low, suggesting that the majority are pre-growth spurt.

Additional to the height data is the fact that there is no significant difference between mean age in months of the two groups. Taken together, the similarity in height and the similarity in age suggests that any difference in performance is most likely attributable to the respective growth of the two groups in the previous six months.

Measures of actual reach

Despite the lack of differences in mean height between children in the High and Low Growth group, the children in the High Growth group managed a longer mean actual reach. However, it should be considered that length of actual reach on this task, as compared, for example to the upward reaching task, is not purely a factor of height. Changes in body proportions associated with the growth spurt may increase reaching distance (i.e. legs make up a greater proportion of overall body height and there may be changes in arm length).

Measures of predicted reach:

However, despite the differences between the groups in terms of actual reach, there was no significant difference between the mean predictions of the High versus the Low Growth group. This suggests that, although their actual reaching ability had increased, children in the High Growth group did not recognize this when making predictions of their reach. Both High and

Low Growth groups recognised that the length of their reach would increase as surface height increased, indicating that both groups were able to detect these affordances. What differed was not their ability to detect the affordances of the different surface heights, but their knowledge of the relationship between their own abilities and the affordances present in the experimental situation.

Relationship between predictions and actual reach:

When the signed difference between predicted and actual reach was examined, it could be seen that the predictions of both groups tended to be overestimates of their reaching ability but that the level of overestimate decreased with increasing surface height. However, the High Growth group's predictions were closer to their actual performance and on the 60cm and 80cm surfaces, their actual reach exceeded their predictions. This pattern is also apparent when the frequency of responses which are over or underestimates for each group are examined: both groups produce more responses which are overestimates, but more overestimates are produced by the Low Growth group. The correlations between predicted and actual reach were examined for each group. These were notably higher for the Low Growth group, again reinforcing the idea that the Low Growth group were better at assessing the relationship between their ability and physical characteristics than were the High Growth group. In fact, when the correlations between predicted and actual reach are examined for the three age groups in Chapter Two, it can be seen that the performance of the 12+13 age group is most similar to that of the High Growth group in the present experiment, with the Low Growth group quite similar to the 10+11 year old children described in Chapter Two.

Mistrials:

However, there is a notable difference between the performance of the High Growth group in this experiment and the 12+13 year old children described in Chapter Two. The 12+13 year old children produced the highest number of mistrials of all three age groups, whereas in this experiment, there was no significant difference between the number of mistrials produced by the High or Low Growth group. However, both performance and prediction are under the control of the individual. Awareness of the effects of the physical changes taking place allows children taking part to adjust either their predictions or their performance. Large overestimates, coupled with an increase in moments of inertia of limb segments, are most likely to be associated with a high number of mistrials: if you act on your prediction, you will pass the point of muscular reversibility (this was seen in the middle age group in Chapter Two). In this case, the mean number of mistrials in both High and Low Growth groups is higher than that reported for the 10+11 and the 14+15 year old children in the first experiment, but slightly lower than that reported for the 12+13 year old children. However, in this experiment, as shown in Table 6.7, the frequency of underestimates was higher in the High Growth group. It is possible that these boys were consciously responding to physical changes of which they were aware and their more conservative predictions may have resulted in lower mistrials.

Overall, the results of the present experiment indicate that there are indeed performance differences which are growth-related. The children who took part were aged 12 and 13, as were the middle age group who took part in the same experiment in Chapter Two. However, in this case, the boys were the same age and of similar height , so it is possible to link the observed differences in performance to the key distinguishing factor: the amount of growth in the previous six months. It is also likely that the differences observed in the present experiment are related to a time lag in perceptuo-motor recalibration in the High Growth group, due to the unusual amount of growth which they have experienced compared to previous years. The next experiment will examine whether these differences are still present when height increases only are taken into account and ability to recognize the limits of muscular reversibility of a forward movement are ruled out.

Chapter Seven

Relationship between growth and performance II: still using the stepladder?

In addition to the test described in Chapter Six, two other experiments were carried out with the group of children whose growth was tracked over a six month period. The present experiment was a replication of the experiment described in Chapter Three, where children were asked to reach up to place an object on a high shelf. This experiment was similar to one carried out by Plumert (1995) and it was considered to be complementary to the previous experiment described in Chapter Six.

Consideration of the results of the forward reaching experiments, described in both Chapters Two and Six, as well as the upwards reaching experiment described in Chapter Three, suggests that children at the rapid growth stage have most difficulty in judging movements which necessitate the movement of the child's centre of mass horizontally, to the point where a vertical line drawn through the child's centre of mass will pass through their base of support. In Chapters Two and Six, the difficulty which children experienced apparently was related to a difficulty in identifying a "zone of muscular reversibility" of the movement" (Carello et al. 1989). It was observed that, as children's age increased, their judgements of their ability became more conservative. However, in addition, children in the 12+13 year old group had a very poor match between their predicted and actual reaches and in the forward reach experiment they produced many more mistrials than the older or younger children.

In the experiment described in the last chapter, this pattern was apparent in the performance of the High Growth group and not the Low Growth group, despite the fact that both the mean age and mean height of children in the two groups was similar. In order to establish whether these differences were confined to this specific type of movement, it was proposed to repeat the upward reach experiment with the High and Low Growth groups.

The predictions, in line with the results from the experiment described in Chapter Three, were that there would be no differences between the High and Low growth groups in terms of maximum reach, maximum predicted reach or measures of difference between maximum reach and predicted reach when reaching was in a vertical direction. These predictions, each of which is effectively a Null Hypothesis, are intended to eliminate simple changes in height as a factor behind poorly coordinated movement in adolescence and provide support for the idea that the movement difficulties observed in the 12+13 year old group are mainly due to the timing of recalibration following changes in body proportions, including changes in height, muscle density and size and changes in the centre of mass of limb segments as well as of the whole body.

Method:

Participants:

118 participants were recruited from six Secondary Schools in the Glasgow City Council Education Department area. Once each head teacher had agreed that the study could take place, a contact teacher identified a number of boys who would meet the criteria specified. These were as follows:

Boys eligible to take part had to be aged 12 or 13 years of age (a small number of participants were aged 14 because of the time lag between the teacher making up a list of suitable participants and the test date). Teachers were informed that the aim was to obtain roughly equal numbers of boys aged 12 and aged 13. It was explained that the aim was to study boys likely to be in the course of the adolescent growth spurt. Teachers were asked to base their selection on the boys' age (not their size). Children with known and diagnosed coordination or movement difficulties were excluded from the sample.

Parental consent was obtained for the boys identified as suitable by the contact teacher. Once parental consent had been obtained, the researcher visited each school and measured each participant. Measurements were taken of total height, arm length from acromium to tip of thumb, leg length from foot to head of femur and foot length from heel to end of big toe. The child was informed that they were taking part in a study of the effects of growth and that the researcher would return in six months at which time they would be measured again and would take part in some short tests.

After a six month interval (timed to coincide with the school summer holidays since growth is greatest during summer months), the researcher returned to the school. Of the 118 children measured in the first phase of the study, 66 completed this test on the second visit. The remaining children were either absent on the second visit or due to time limitations, only completed the other two tasks. Each child was measured in exactly the same way as during the first visit and in addition a measurement of height to shoulder was taken to allow anthropometric reaching height to be calculated.

Each child's height at first visit was subtracted from their height at second visit, giving a measure of growth during the six month period. Children were then divided into high and low growth groups. The High growth group (n= 15) grew between 4 and 8 centimetres during the six months whereas children in the low growth group (n= 38) grew between zero and 2.9 centimetres. Thirteen children grew between 2.9 and 4 centimetres and were excluded from the sample. Although there was considerable overlap, some children participating in this experiment did not complete Experiment Five and some children who completed Experiment Five did not complete the present experiment.

Table 7.1: Participant details.

Group	Mean Age (years and months)	Age Range	Mean Height, 1st visit	Mean Height, 2nd visit
High Growth n = 15	13 years (sd 5 months)	12 years, 3 months - 13 years, 10 months.	152.3 (sd7.76)	157.2 (sd7.82)
Low Growth n = 38	13 years and 2 months (sd 8 months)	12 years, 1 month - 14 years.	158.3 (sd9.65)	159.7 (sd9.66)

Materials:

The materials consisted of a shelf (20cm x 30cm) mounted on a shelf bracket which could be attached at different heights to a shelving strip held by the experimenter. In each location where testing took place, a position where it could be determined that the shelf bracket was always held vertical was selected. This was usually a room corner. A small cylindrical piece of wood, diameter 4cm, served as the target object which participants were asked to place on the shelf. The experimenter held a score sheet with details of the participant's name, date of birth and height. The shelving strip was coded for two groups of subjects - those above 1metre 55cm and those below 1metre 55cm and the height measurement on the score sheet determined which set of heights the experimenter used. This division was based on examination of the reaching height (height to shoulder plus arm length from acromium to tip of thumb) of a pilot group.

The score sheet was marked with a set of coded letters corresponding to the marks on the back of the shelving strip (which were not visible to participants). These coded letters were nine shelf heights, presented three times to each participant in randomised order. The heights were calculated to contain at least 2 unreachable heights for all participants and at least 2 easily reachable heights for each participant. This was possible by using two overlapping height sets. The two height sets were as follows:

A (boys under 155cm): 149.5cm, 156cm, 162cm, 168.5cm, 175cm, 181cm, 187.5cm, 194cm, 200.5cm.

B (boys 155cm and over): 194cm, 200.5cm, 206.5cm, 213cm, 219cm, 225.5cm, 232cm, 238.5cm, 244.5cm.

Procedure:

Participants were initially told that they would be taking part in three experiments designed to test balance and their judgements of height. One third of the participants completed the present experiment first and two thirds completed one or two other experiments first. Participants were asked to approach the apparatus and wait until the experimenter explained the rules of the test to them. The experimenter gave each participant the following instructions:

"This is a kind of guessing game. Before you begin, I'll tell you a few things about it. I'm going to move this shelf up and down. The aim is for you to tell me at which heights you could put this object on the shelf. There are a couple of rules you should remember when you're guessing. You won't be allowed to jump, but you can stand on tiptoes. You must place the object on the shelf, not throw it. Any questions about these rules?

Before you try reaching, I want you to tell me which of the shelves you think you can reach. I'll show you the shelf at different heights twenty-seven times altogether and each time you should say yes if you think you can put this on top and no if you think it's too high. It's important that you don't try it out until I ask you to at the very end. Have you any questions about that or would you like to start?

Here's the first height. Do you think you could put it on this shelf?

Following the instructions, the experimenter presented three blocks of trials of the nine shelf heights, each block with the nine shelf heights presented in randomised order. The participant's response was marked down against each height.

Although instructed to answer yes or no, some participants responded by saying that they were unsure - this was marked as a "Don't Know". During coding, "Don't Know" was coded as no, since the participant had not given an affirmative response.

When the participant had responded to each of the 27 presentations, the experimenter handed them the target object. The first shelf height presented was the lowest shelf height the participant had previously said they could not reach. The shelf was then moved up or down to determine the highest shelf that the participant could reach and the experimenter noted this height.

Results:

Initially, a comparision of the mean age in months and mean height of children in the two growth groups was examined. Following this, the results were examined in terms of maximum reach for children in both groups, predictions of maximum reach, predictions and anthropometric reaching height, measurements of constant error and proportion of over- and under-estimates in each group.

Differences between groups:

An analysis of the height and age of children in the High Growth group and Low Growth group was carried out. Mean height and mean age in months of children in the two groups is shown in Table 7.1 above. There were no significant differences between the mean height at date of test of the two growth groups (t=0.99, n.s.), although the mean height of the Low Growth group was slightly higher than for the High Growth group. The differences between the means at date of testing was however considerably less than the differences between the mean group heights at date of first measurement. This, together with the slightly higher variance in the Low Growth group, suggests that some children in this group were post-growth spurt.

Mean age was also examined. Again the mean age for the Low Growth group was 2 months higher than that of the High Growth group, but this difference between the means was not significant (t=1.06, n.s.)

Maximum reach:

Table 7.2 gives the mean maximum reaching height for the children in the High and Low Growth groups. Children in the Low Growth group demonstrated a higher maximum reach than did children in the High Growth group and the standard deviation was lower for the latter group. This most likely reflects the height and height variability of the two groups, with the High Growth group being slightly smaller overall with less variability in height. However, again similar to differences in the children's heights, described above, a Student's t-test showed that the difference between mean maximum reach was not significant (t=0.24, n.s.).

Table 7.2: Mean reach height in centimetres for children in the High Growth group and Low Growth group. Reach height is the highest shelf height successfully attained by each child.

	Mean	**sd**
High Growth group	202.4	12.26
Low Growth group	207.1	14.05

Children's predictions of their maximum reach:

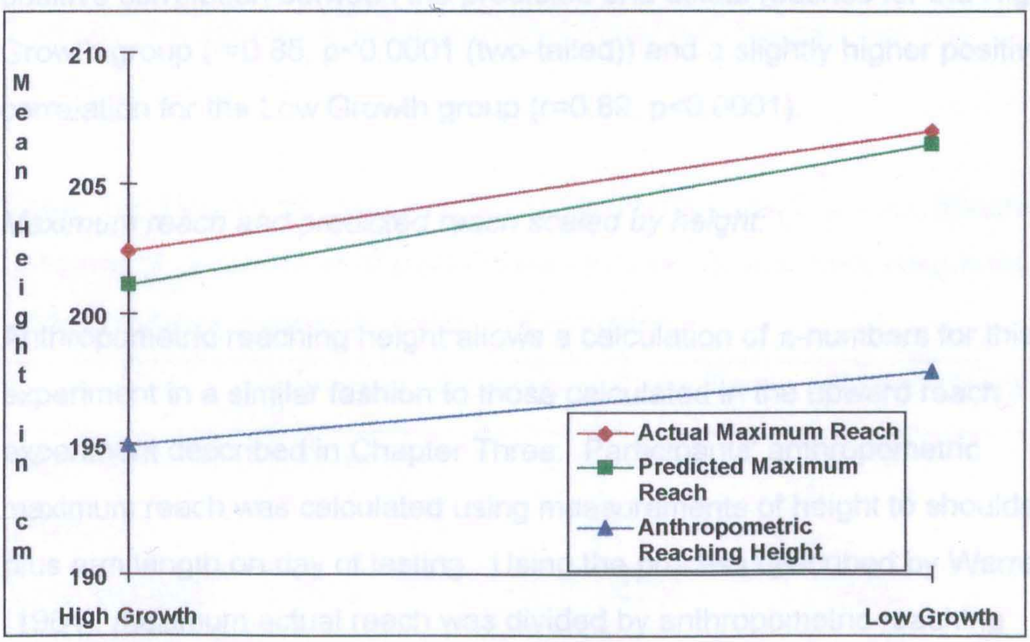
Children were asked to predict which shelves they would be able to reach and which shelves would be too high for them to reach. Table 7.3 below gives means and standard deviations for the children's predictions of their maximum reach for both High and Low Growth groups.

Table 7.3: Mean maximum predicted reach, based on the highest shelf on which each child predicted they could place the target object (heights are in centimetres).

	Mean	sd
High Growth group	201.1	13.95
Low Growth group	206.5	16.22

Again, the increase in children's predicted reaches reflects the height differences between the two groups. The difference in mean maximum predicted reach between the two growth groups was examined using a Student's t-test. This difference was not significant (t=1.20, n.s.).

Figure 7.4: Comparision of the mean maximum actual reach made by children in both High and Low Growth groups with their maximum predicted reach and with their anthropometric reaching height.



Measures of difference between maximum reach and predicted reach:

It was of particular interest to study the differences between the highest shelf the children reached and their predictions. This difference gives an indication of the type of predictions made by the children. There were no significant differences between the groups on the absolute mean number of centimetres between actual and predicted reaches (mean, High Growth group: 5.53cm, sd 4.73; Low Growth group: 5.13, sd 5.44). When the direction of the difference was examined, there were more noticeable differences between the groups: mean signed difference for the High Growth group was -1.27cm (sd 7.31) and for the Low Growth group the mean signed difference was -0.55 (sd 7.51). However, these differences were not significant ($t=0.32$, n.s.).

An examination of the relationship between the predicted and actual reaches for each group was carried out. This showed that there was a signifcant positive correlation between the predicted and actual reaches for the High Growth group ($r=0.85$, $p<0.0001$ (two-tailed)) and a slightly higher positive correlation for the Low Growth group ($r=0.89$, $p<0.0001$).

Maximum reach and predicted reach scaled by height:

Anthropometric reaching height allows a calculation of π-numbers for this experiment in a similar fashion to those calculated in the upward reach experiment described in Chapter Three. Participants' anthropometric maximum reach was calculated using measurements of height to shoulder plus arm length on day of testing. Using the process described by Warren (1984), maximum actual reach was divided by anthropometric reaching height for each individual and group means were obtained. It was also possible to compare these π-numbers with scaled predicted reach - where maximum predicted reach was divided by anthropometric reaching height. The means and standard deviations are displayed in Table 7.5 below.

Table 7.5: Mean π-numbers (maximum reach scaled by anthropometric reaching height) compared with mean scaled predicted maximum reach for each growth group.

	π-number	sd	Scaled Prediction	sd
High Growth group	1.0395	0.0335	1.0326	0.0372
Low Growth group	1.0472	0.0244	1.0441	0.0430

A Student's t-test comparing mean π-numbers for each age group showed that the small differences between groups was not significant (t=0.80, n.s.). Similarly, the difference between scaled Predicted Reaches was not significant (t=0.97, n.s.).

Table 7.6: Degree of accuracy for participants in each group, described in terms of percentage of participants in each group who, respectively, underestimate, overestimate or are accurate.

	Underestimated	Zero Error	Overestimated
High Growth group	40%	33%	27%
Low Growth group	29%	42%	29%

It was also interesting to examine the nature of the estimates of the two groups in terms of accuracy. The frequency of participants in each group who underestimated, overestimated or were accurate (i.e. estimate=actual) was obtained.

These data are set out in Table 7.6. However, a Chi-square analysis could not be performed on these data since expected frequencies of two cells was less than 5.

Discussion

The results of the present experiment were considered in terms of the differences between the groups, their maximum reach, predictions of maximum reach, difference between maximum reach and predicted reach and the effect of scaling maximum reach and predictions by the child's height. Each of these will be interpreted below, followed by a short discussion of the implications of these results.

Differences between groups:

Both height and age of the children in the groups designated High Growth and Low Growth were compared. Unlike Experiment Five, the Low Growth group were taller than the High Growth group both at date of first measurement and at date of testing. However the difference between the two groups was much less on date of testing, indicating that the High Growth group had indeed grown much more during the intervening six months. The slightly higher variance in the Low Growth group also suggests that this group contained some children who were pre-growth spurt as well as some who might have already experienced a growth spurt (it was unlikely that they were in the course of a growth spurt, however, given the low growth during the previous six months). There was no significant difference between the height of the two groups on date of testing and differences in height were not age related, since there was no significant difference between the mean age in months of the two groups.

Maximum reach:

Measurements of maximum reach in an experiment which involves reaching upwards to place an object on a high shelf are more likely to reflect differences in height of participants than are measurements of maximum reach in experiments which involve forward displacement of the indivdual's centre of body mass. In the case of the present experiment, this is exactly what is observed. The differences in maximum reach between the two groups reflect the small differences in height between the two groups taking part, even to the extent that the variance, as well as the mean maximum reach, is higher in the Low Growth group. However, similar to the differences in heights, there was no significant difference between mean maximum reach between the two groups. There are a number of possible explanations for the small differences which do exist between the means. For example, strength and flexibility may be temporarily affected by a growth spurt: children undergoing a growth spurt experience bone growth and this can put considerable pressure on joints and muscle lengths (Faulkner & Tanner, 1986).

Children's prediction of their maximum reach:

Children in both the High and Low Growth groups predicted the highest shelf they could reach before attempting actual reaches. Again, the Low Growth group, who were slightly taller, predicted that they could reach slightly higher shelves than the High Growth group and again the variability of predicted reach was higher in the Low Growth group. However, the small differences between the two groups were not significant. At this point, the similarities between the two groups are noticeable and contrast strongly with differences in maximum reach and maximum predicted reach between the two Growth groups in the previous experiment, which involved forward reaches. The lack of differences between the two groups in the present experiment provides support for the idea that the type of movement most difficult for children undergoing a growth spurt is not one which involves a simple estimate of distance relative to their own physical characteristics, but one which involves maintaining balance while performing a forward reach, or a movement which allows the individual's centre of mass to be displaced horizontally rather than vertically as in the present experiment.

Measures of difference between maximum reach and predicted reach:

The difference between the predictions and the actual maximum reaches of children in the High and Low Growth groups was examined. The means for the absolute difference between estimate and actual reach were very similar, but there was a directional component as indicated by the signed difference. The High Growth group tended to underestimate relative to their actual maximum reach, whereas the mean signed difference for the Low Growth group was very close to zero. Both scores were most similar to the performance of the 12+13 year old children in Experiment Two. Additionally, in the present experiment, differences between the High Growth group and the Low Growth group were not significant.

Maximum reach and predicted reach scaled by height:

Dimensionless π-numbers as obtained by Warren (1984) were obtained and again, there were only very small differences between groups and in fact, these differeces were not signficant. Thus, when anthropometric reaching height for each child is taken into account, it is clear that children in both High and Low Growth groups are detecting the same invariant pattern in the environmental layout relative to their own characteristics. A comparison of the π-numbers obtained for the High and Low Growth groups in this experiment are very close to the π-numbers obtained for all three age groups in the similar experiment described in Chapter Three.

There was, however, a greater tendency for the predictions of children in the High Growth group to be underestimates relative to the predictions of children in the Low Growth group. The High Growth group produced 11% more responses which were underestimates than did the Low Growth group and the Low Growth group produced 9% more responses which were accurate. These results form a similar pattern to that observed in the last experiment, although in this case, the results could not be examined by Chi-square due to low expected frequencies. The higher frequency of underestimates again suggests that, following a period of rapid growth, children in the High Growth group had not fully completed a recalibration which would allow them to make accurate predictions about a vertical reaching action.

Overall, the results provide support for the idea that, although children at around age 12 or 13 are beginning to produce more cautious judgements - a trend which has been observed in the first three experiments - they are capable of producing quite accurate estimates of their ability provided they do not have to take into account movement which may affect their stability and upright position. The small differences between the High and Low Growth group were differences which were entirely in line with the differences in their height and the two groups were very similar in composition with the exception of the amount of growth in the previous six months. The trend towards more cautious judgements is likely to be explained in part by the fact that children during or just after the growth spurt are more likely to reach further than they predict, given the changes in body proportions which they have just experienced. In addition and similar to the findings of the last experiment, children who have completed a growth spurt will not need to overestimate in order to improve their movement skills to the same extent as would be predicted for a younger and pre-growth spurt child.

Chapter Eight

Relationship between growth and performance III: Gone fishin'!

Increasingly, the focus of this thesis has been on the way rapidly growing children respond to changes in their centre of gravity and the centres of gravity of their limbs. The previous experiment demonstrated that very little difference existed between the performance on an upward reaching task between children who had grown rapidly over the preceding six months and those who had grown only a little. This contrasts strongly with the results of the experiment described in Chapter Six. When the task involved a forward reach, there was a much better match between the predictions and the actual reach of children in the Low Growth group than between the predictions and actual reach of children in the High Growth group. Additionally, it was of particular interest that children in both groups predicted very similar performances but that the High Growth children managed to reach slightly further than they predicted. Hence, a task which requires children to identify the limits of their zone of muscular reversibility produces notable differences between the groups.

The final experiment attempts to highlight this difference between children in the High Growth and Low Growth groups. Manipulating reach by using an unfamiliar tool to extend arm length changes the moments of inertia in a forward reach, while simultaneously rendering the reacher uncertain about the maximum length of reach possible. Where the reacher is a child who already has difficulty in identifying the limits of their zone of muscular reversibility, it is likely that adding a weighted pole to the forward reaching task will make it even more difficult for the child to maintain balance while reaching.

Tasks where moments of inertia are manipulated appear frequently in the literature. In fact, the ability of the haptic system to use the moments of inertia of the upper limb as an invariant which can indicate limb and limb segment position has recently been proposed (Turvey & Carello, 1995).

However, such a task is a relatively unfamiliar one. The calibration of our perceptuo-motor system is likely to be subject to periodic drift and the necessity for recalibration: this is the case in adults as well as in rapidly growing children. Well practiced movements appear graceful and well coordinated, but a task which we have not performed for some time can be performed clumsily. An expert typist who has not used a keyboard for some time **knows** how to type, but must relearn the sensation of typing in order to return to their previous standard.

Is it likely that recalibration in rapidly growing children takes place without any noticeable performance lag for well practiced tasks, but is highlighted in less frequently performed actions? If this is indeed the case, the unfamiliar nature of the present task, in contrast to the relatively well practised action of reaching out to place a book on a shelf or cutlery on a table, should result in poorer performance for the child who has undergone a recent growth spurt.

Two main predictions were made with respect to the present experiment. The first prediction was that the High Growth group would be in the process of adapting to changes in their moments of inertia and would thus be less accurate in their predictions of their maximum reach using both short and long poles than the Low Growth group. This would also be apparent in the match between their predictions and actual reaches.

The second prediction was that the High Growth group would find it more difficult to recognize the limits of their zone of muscular reversibility and as a result more mistrials would be observed in this group.

Method:

Participants:

118 participants were recruited from six Secondary Schools in the Glasgow City Council Education Department area. Once each head teacher had agreed that the study could take place, a contact teacher identified a number of boys who would meet the criteria specified. These were as follows:

Boys eligible to take part had to be aged 12 or 13 years of age. Teachers were informed that the aim was to obtain roughly equal numbers of boys aged 12 and aged 13 and it was explained that the aim was to study boys likely to be in the course of the adolescent growth spurt. Teachers were asked to base their selection on the boys' age (not their size). Children with known and diagnosed coordination or movement difficulties were excluded from the sample.

Parental consent was obtained for the boys identified as suitable by the contact teacher. Once parental consent had been obtained, the researcher made the first of two visits to each school and took measurements of each participant. Measurements were taken of total height, arm length from acromium to tip of thumb, leg length from foot to head of femur and foot length from heel to end of big toe. The child was informed that they were taking part in a study of the effects of growth, and that the researcher would return in six months at which time they would be measured again and would take part in some short tests.

After a six month interval (timed to coincide with the school summer holidays since change in height is greatest during summer months), the researcher returned to the school. Of the 118 children measured in the first phase of the study, 74 were seen on the second visit. Each child was measured in exactly the same way as during the first visit.

Each child's height at first visit was subtracted from their height at second visit, giving a measure of change in height during the six month between first and second visits. Children were then divided into high and low growth groups. High growth group (n= 23) grew between 5 and 9 centimetres during the six months whereas children in the low growth group (n= 32) grew between zero and three centimetres. Twenty children grew between 3 and 5 centimetres, and these were excluded from the sample.

Table 8.1: Participant details.

Group	Mean Age (years and months)	Age Range	Mean Height, 1st visit	Mean Height, 2nd visit
High Growth n = 23	13 years and 2 months (sd 5 months)	12 years, 4 months - 13 years, 10 months.	156.26 (sd11.6)	162.5 (sd11.4)
Low Growth n = 32	13 years (sd 8 months)	12 years, 1 months - 14 years.	157.0 (sd 9.39)	158.6 (sd 9.26)

Materials:

The materials used in the present experiment consisted of four mats which were 1.6 metres in length. Two of the mats had a total of 16 marks at 10cm intervals along their length. On each mat marks were assigned a random number between one and sixteen, with the constraint that no two numbers should appear in sequence. On the remaining two mats, each mat had a total of 14 marks at 11cm intervals along the length and on each mat, marks were randomly assigned numbers between one and fourteen, again with the constraint that no two numbers should appear in sequence.

Additionally, two poles with cup hooks on one end and a tape handle on the other end were used. One of the poles had a diameter of 2.5cm and length of 65cm and the other pole had a diameter of 2.5cm and a length of 80cm. The poles were used to pick up and place a small brass weight of 50g, which had a hole to allow it to be picked up using the hook on the end of each pole.

The experimenter had a set of score sheets which listed instructions for the task, the order of testing and which pole to use and included separate spaces for recording mark predicted and mark reached as well as mistrials.

Procedure:

On arrival at the test site, the experimenter taped the mats to the floor in a cross formation. The cross was then bisected with masking tape, giving a spot for the participant to stand while performing the task. Both poles and the weight were positioned on a small table near the mats. When each subject arrived the experimenter explained the test to them as follows:

"This is what I'm going to ask you to do. I have two poles here with hooks on one end and a handle on the other end. I'm going to ask you to guess how far along these mats you could reach to place this weight down on each of the mats using the poles. Then I'm going to ask you to try it out. You have to stand on this cross in the centre of the mats and you can't step forward on to the mat or put your free hand down to help you balance. If you do this you will have to try again. It's OK for you to bend your knees and move your free arm to help you keep your balance as long as you don't step forward or put your hand on the floor. Have you any questions about the rules?

It can be a bit difficult to get the weight on and off the hook at the end of the pole. Here's the first pole: try hooking the weight and lifting it off the table *and placing it back and unhooking it a few times. Well done. Please stand in the centre of the mats now, facing the Mat 1. Hold the pole with one hand at each end while you're making your guesses. Now, without trying it out, which mark is the furthest you think you could reach one this mat with this pole?"*

Once all the estimates were made with the first pole, the experimenter then repeated the procedure with the second pole, including a practice hooking and unhooking session. This was designed to give the participant some experience of wielding the pole without performing a reach along one of the mats with it.

When all the estimates were completed, the experimenter handed the first pole back to the participant and asked them to try placing the weight down on the furthest mark they could reach. At this point, participants were reminded that they should not place their free hand on the floor to maintain balance and that they should not step off the mark in the centre of the mats. Where they did this, the experimenter recorded a mistrial and asked them to try again. Only when they had completed a reach on a particular mat without a mistrial did the experimenter note the reach made and allow them to move on to the next mat.

All participants performed estimates and reaches in the order: Mat 1, Mat 2, Mat 3 and Mat 4. However, the order in which they used the poles alternated between subjects, with odd numbered participants using the Long Pole first and even numbered subjects using the Short Pole first.

Results:

In terms of the predictions that children in the High Growth group should find it most difficult to cope with a task which adds additional demands to their ability to identify and control their performance around the limit of their zone of muscular reversibility, a number of difference aspects of the respective performance of both High and Low Growth groups will be examined. First, the age and height of both the Low Growth and High Growth groups will be examined, in order to determine whether any observed differences in performance on the test may be due to differences in age or height. Second, the performance of the two groups will be examined, to determine how far they reached using both long and short poles. Differences between the two growth groups in terms of their predictions will then be examined, followed by an examination of the difference between predictions and actual reach. Third, the number of mistrials, where participants lost balance during the reach, will be examined and fourth, the correlations between predicted reach and actual performance on the task will be examined separately for each group.

Age and height of children in each group:

Although children were selected because they were either twelve or thirteen years of age, the mean age in months (see Figure 8.1) of the High Growth group and the Low Growth group was examined using a Student's t-test. The small difference between the two groups was not a significant one (t=0.87, p=n.s.) implying that any performance differences between the children would not be due to differences in age. Height differences might also result in performance differences, so a Student's t-test was also carried out on the mean height of children in each group. The differences between the mean height for children in the High Growth group and children in the Low Growth group (as listed in Table 8.1 above) were not significant differences (t=1.41, p=n.s.). These heights were the height on the date of the experimenter's second visit (i.e. the date the children performed the test). It is thus unlikely that differences in performance between the High Growth group and Low Growth group were due to differences in age or height. The main factor which distinguished children in the two groups was the amount of growth in the six months previous to the day on which they performed the test.

Performance differences on the tests:

The predictions of maximum reach made by children in both the High Growth group and the Low Growth group were examined. Mean Predicted reach for both groups using short and long poles are shown in Tables 8.2 and 8.3 below. In both cases, children in the High Growth group predicted that they would reach further than children in the Low Growth group. A 2 x 2 ANOVA examining both pole lengths and both growth groups showed that the differences in predictions between the children in the two groups was a significant difference ($F(1,53)=8.40$, $p<0.005$). Additionally, there was a significant effect of pole used ($F(1,53)=459.81$, $p<0.0001$) and a significant interaction between pole used and group ($F(1,53)=5.22$, $p<0.026$).

When the mean actual reach for children in the Low Growth group and the High Growth group were compared (Tables 8.2 and 8.3 below), it can be seen that the differences between groups, though in the same direction as for mean predicted reach, are rather smaller. In fact, a 2 x 2 ANOVA showed that the difference between the mean actual reach for children in the High Growth group and the Low Growth group was not significant ($F(1,53)=2.45$, n.s.) although the mean actual performance where the long pole was used was significantly greater than when the short pole was used ($F(1,53)=861.91$, $p<0.0001$). There was no significant interaction between pole used and group ($F(1,53)= 0.01$, n.s.).

Table 8.2: Mean Actual Reach, Predicted Reach and Difference between Predicted and Actual Reach for children in both High and Low Growth groups using the short pole (60cm).

	Actual Reach		Predicted Reach		Signed Difference	
	Mean	sd	Mean	sd	Mean	sd
Low Growth	110.7cm	11.2	115.3	14.3	4.58	11.8
High Growth	115.0	9.0	124.1	14.4	9.11	14.1

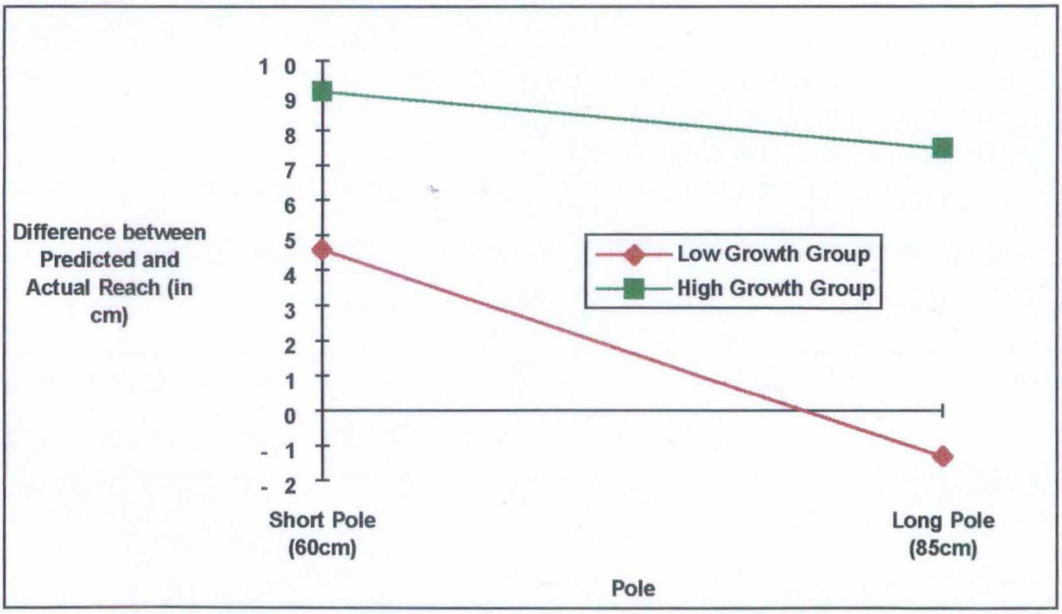
Table 8.3: Mean Actual Reach, Predicted Reach and Difference between Predicted and Actual Reach for children in both High and Low Growth groups using the long pole (85cm).

	Actual Reach		Predicted Reach		Signed Difference	
	Mean	sd	Mean	sd	Mean	sd
Low Growth	133.8	10.8	132.5	14.2	-1.33	12.4
High Growth	138.0	9.6	145.4	13.7	7.48	13.4

Relationship between Predictions and Actual Reach:

When the relationship between predicted and actual reach is examined, it can be seen that the mean predicted reach of children in the High Growth group exceeds their mean actual reach for both long and short poles. This is still the case for the Low Growth group using the short pole, though to a lesser extent. The mean predictions of the Low Growth group using the long pole are actually slightly less than their actual reach.

Figure 8.4: Signed difference between Predicted Reach and Actual reach for both High and Low Growth groups, using the short pole (60cm) and the long pole (85cm).



A 2 x 2 ANOVA was carried out on the differences between predicted and actual reach for children in the High and Low Growth group (between-subjects factor) using both long and short poles (within-subjects factor). The differences between High and Low Growth groups was a significant one ($F(1,53)=3.97$, $p<0.05$), as was the difference between performance using

Long and Short Poles ($F(1,53)=13.56$, $p<0.001$). Finally, there was a significant interaction between growth status and pole used ($F(1,53)=4.36$, $p<0.042$). The difference between predicted and actual reach for both High and Low Growth groups is presented in Figure 8.4.

An examination of the correlation between predicted reach and actual reach for children in both High and Low Growth groups was also carried out. The difference between Predicted and Actual reach showed that the children in the Low Growth group were less likely to overestimate their reaching ability: how closely did their predictions match their performance? The Pearson correlation coefficients between Predicted and Actual Reach in both groups are displayed in Table 8.5 below, showing that there was a higher correlation between the predictions and actual reach of children in the Low Growth group using both Long and Short poles.

Table 8.5: Correlation between Estimated and Actual Reach for children in both High and Low Growth groups at each surface height.

	Short Pole (60cm)	**Long Pole (85cm)**
Low Growth Group	0.60 ($p<0.0001$)	0.54 ($p<0.001$)
High Growth Group	0.34 (n.s.)	0.38 ($p<0.07$)

Finally, the frequency of occurrence of accurate responses, overestimates and underestimates for children in both groups was examined. A Chi-square showed that there was a significant relationship between growth status and likelihood of producing a certain response ($\chi^2=9.90$, $p<0.007$). The percentage of responses in each category is shown below in Table 8.6.

Table 8.6: Percentage of responses which were either over or under estimates for both High and Low Growth groups (combined data from long and short poles).

	Underestimates	Accurate (Zero Difference)	Overestimates
Low Growth Group	42%	14%	44%
High Growth Group	33%	0%	67%

Mistrials:

A count was kept of the number of mistrials of all children and the differences in number of mistrials for children in the High Growth group and children in the Low Growth group was examined. The mean number of mistrials for the High Growth group was 2.57 (sd 2.76) and the mean number of mistrials for children in the Low Growth group was 1.10 (sd 1.48). A Student's t-test indicated that the difference between these means was significant ($t=34.29$, $p<0.03$).

Discussion:

The Results section above considered the data originating from this test with two groups of 12 and 13 year old boys under a number of headings. Each of these headings will now be discussed in turn, followed by a commentary on what the overall implications of these results are likely to be.

Age and height of children in each group:

Analysis of the age and height of the children in both the High Growth group and the Low Growth group showed that the small differences in mean height and mean age in months were not significant. The age range was similar, with the Low Growth group having a slightly wider age range. These similarities suggest that any group differences in performance are due to the differences in growth during the six months preceding the day the children performed the reaching task. The High Growth group grew between 5 and 8cm during this time and the Low Growth group grew between zero and 3cm.

Performance differences on the tests:

In the case of the present experiment, there were clear performance differences between the groups. The actual reaching performance of the children in both High and Low Growth groups was not significantly different, but their predictions of their performance were significantly different. High Growth children tended to overestimate the increase in reach afforded by both long and short poles. However their estimate was not matched by their ability - not only did they overestimate, but, as discussed below, they were more prone to mistrials during reaching. In contrast, the Low Growth group were fairly accurate about the increase in reach afforded by both poles.

Relationship between Predicted and Actual Reach:

When the relationship between predictions and actual reach was examined in more detail, a more complex pattern emerged. Children in the High Growth group tended to overestimate their ability equally with both short and long pole, whereas children in the Low Growth group were noticeably more conservative in their estimates of their reach when using the long pole, but overestimated their reach slightly on the short pole. In fact, overall the predictions of the Low Growth group were closer to their actual performance, when difference between prediction and actual reach was examined.

These results suggest that the children in the High Growth group do indeed find it more difficult to predict their performance when required to use tools to extend their reach. Since they have recently experienced major changes in height, limb length and moments of inertia, placing a tool in their hand which further increases their moment of inertia in the action which they are required to make affects both their ability to judge appropriate actions as well as their actual performance: they fail to identify this. In comparison, the performance of the Low Growth group is more conservative overall, and they are clearly sensitive to the different increase in the moments of inertia resulting from the use of the long pole compared to the short pole.

More detailed inspection of the nature of predictions shows that the groups also differ significantly on this measure. Most notably, the Low Growth group are evenly split between over and underestimates of their ability with 14% accurate judgements. However, the High Growth group predominantly overestimated their ability and produced no accurate predictions at all. The correlation data adds to this picture: there was a much closer relationship between predictions and actual reach for children in the Low Growth group, with only quite low and for the short pole, non-significant, correlations between predicted and actual reach for the High Growth group.

Mistrials:

In experiment one, it was noted that the 12 and 13 year old group combined a tendency to overestimate their ability with an increase in mistrials. This would appear to be related to the nature of the task: reaching forward to place a small object on different height surfaces. When a child overestimates, a vertical line drawn through their centre of mass is likely to pass outside their base of support, leading to instability. Up to this point, they can use muscular forces to regain an upright posture, but beyond this point this is increasingly difficult. In experiment one, the overestimates made by this age group were accompanied by an increase in the number of mistrials. A similar pattern can be observed in the present experiment. The High Growth group overestimated their ability more than did the Low Growth group. More mistrials were recorded for the High Growth group. It seems that the more conservative approach in evidence in the Low Growth group is one which minimises mistrials, allowing the children to safely regain an upright position. Similarly, when moments of inertia have changed a great deal, an overestimate risks taking the actor into unfamiliar territory: will they be able to return to their previous posture? In this case, the children were less able to do this. It would appear that where overestimation of ability is accompanied by recent rapid growth, mistrials are likely to increase.

However, discussion in earlier chapters has centred around the fact that overestimation is probably necessary for development (Plumert, 1995). If the High Growth group were not overestimating in this situation, it is difficult to see how they would manage to recalibrate their perceptuo-motor systems to cope with the change. In fact, the pattern observed in the present experiment shows that the children who were most likely to need to recalibrate their perceptuo-motor systems (as a result of recent growth) were most likely to overestimate their abilities in this unfamiliar task. Those who had not grown so much recently were more conservative in their predictions, minimising the risk of mishaps and possible injury.

Chapter Nine

Summary & Conclusions

The primary question which this thesis aimed to investigate was whether problems with movement coordination could be observed in young adolescents. However, in addressing this question, a number of additional and related issues were discussed. Since a discussion of the coordination of adolescents involved comparison with children of other ages, it was possible to extend a line of research which had investigated perception of affordances in adults and in children up to twelve years of age. In studying the perception of affordances in children and adults, a well investigated theme was the tendency for all groups to overestimate their abilities. Finally, the exact physical changes associated with the adolescent growth spurt which are most likely to result in poorly coordinated movement were investigated.

This thesis has addressed all these issues: in some cases, it provides insights which allow the questions above to be addressed and in some cases it helps to provide a clearer understanding of the nature of the questions which remain. For example, the results described in this thesis raise questions relating to another issue: is recalibration the same process in children coping with physical growth and in adults coping with temporary changes in their physical characteristics? This section will look at the findings of the seven experiments discussed in the preceding chapters and how they address the issues outlined above.

Previous research on children's perception of affordances has suggested that young children tend to overestimate their abilities more than adults do (McKenzie & Forbes, 1992, McKenzie et al., 1993, Plumert, 1995, Plumert &

Schwebel, 1997) but that the amount of overestimation decreases with increasing age. During the first three experiments of the present thesis, the youngest age group (ten and eleven year old boys) consistently produced responses which were overestimates of their ability. An examination of the performance of the oldest children studied (fourteen and fifteen year old boys) showed that these children were considerably less likely to overestimate their abilities.

This trend, independent of average group height, was also clearly apparent in the experiments described in Chapters Three and Four, involving judgements of upward reach and step length respectively. The predictions of the oldest children were considerably more conservative than those of the youngest children. Plumert (1995) has suggested that this may be beneficial. The developing child must trade off the drive to attempt actions at and beyond the limit of their current ability against the risks involved in failure. However, at some point in development, a more stable adult pattern must emerge. The time when this is most likely to occur is the time when growth begins to slow and the process of tuning and recalibrating the perceptuo-motor system requires smaller adjustment.

This would lead to the conclusion that, around this time, skill and motor ability would increase noticeably. In boys, this is the case: sporting achievements begin to increase just after the adolescent growth spurt. This is likely to be a result of a combination of factors, including the attainment of adult stature, the increase in muscle size and the ability to develop a skill without having to allow for changing physical parameters. The findings reported in chapters two, three, four and five provide evidence that a transition to an adult mode occurs in boys in early adolescence and that it is associated with the increase in stability which results in learning to cope with and exploit changes in body moments of inertia.

However, evidence such as that provided by Jensen's (1981) study of moments of inertia indicates that children around the age of the adolescent growth spurt may be an exception to this trend towards more accurate assessments of ability. The literature on growth during childhood indicates that boys' rate of growth increases sharply at around the time of their thirteenth birthday and that the same process occurs about two years earlier for girls. Since this physical change is a very major one, involving not only an increase in stature, but also changes in muscle size, limb length, centres of mass of the body and limbs and changes in the overall ratio of trunk/limbs, it seems most likely that this is the age when some deterioration in perception/action links would be observed.

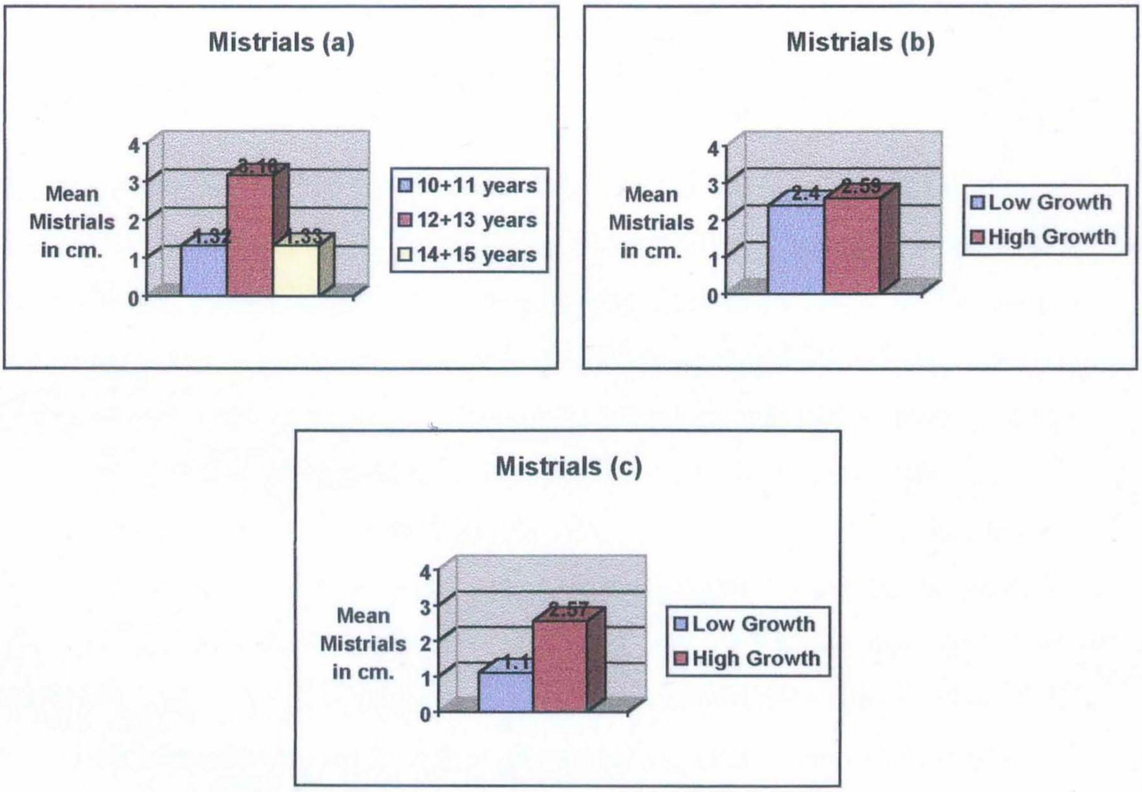
The amount of retuning and recalibration of the perceptuo-motor system which a child must undertake as a result of this growth is likely to result in a process which can be observed experimentally. The first experiment described in this thesis (Chapter Two) showed that the performance of boys at the age most closely associated with a growth spurt differed in a number of ways from that of older or younger boys. The forward reaching task required the boys to identify the limits of their zone of muscular reversibility (as proposed by Carello et al., 1989). The performance of the twelve and thirteen year old boys indicated, by the poor match between their predictions and actual reach (illustrated in Table 9.1 below) and by the number of times they lost balance (Figure 9.2 below), that they were not correctly identifying the limits of their actions in this task.

Table 9.1: Pearson Correlations between Predicted and Actual Reach for all forward reach experiments (Chapters 2, 6 and 8).

Chapter 2	**20cm Surface Height**	**40cm Surface Height**	**60cm Surface Height**	**80cm Surface Height**
Age 10+11	0.56	0.57	0.55	0.43
Age 12+13	0.36	0.39	0.44	0.53
Age 14+15	0.61	0.62	0.58	0.70
Chapter 6				
Low Growth	0.46	0.59	0.71	0.58
High Growth	0.00	0.24	0.40	0.58
Chapter 8	**60cm (Short Pole)**		**85cm (Long Pole)**	
Low Growth	0.60		0.54	
High Growth	0.34		0.38	

It became clear that the degree of recalibration necessary following a growth spurt was the most likely explanation for the poorer performance of these boys. This was explored in detail in the three longitudinal experiments (Chapters Six, Seven and Eight), where the amount of growth in six months of twelve and thirteen year old boys was measured and their performance examined. The boys whose high growth indicated a growth spurt were poorer at identifying their movement abilities than were the boys of the same age whose growth rate was lower (Pearson correlations for Chapters Six and Eight are shown in Table 9.1 above). However, the importance of the range of physical changes associated with the growth spurt, as distinct from simple changes in height, became more apparent. The performance differences between High Growth and Low Growth boys was much less apparent when the task involved an upward reach than when it involved taking account of changes in limb length and moments of inertia (a forward reach, or a forward reach using poles). These performance differences are apparent on examination of the boys' performance in the forward reach experiments in Chapters 6 and 8 (Table 9.1), however performance differences are also observed when mistrials are examined. Table 9.2 below shows the mean number of mistrials for all the forward reach experiments (Chapters 2, 6 and 8).

Figure 9.2: Mean number of mistrials for three age groups (a: Chapter Two) and High and Low growth groups (Chapters 6 (b) and 8 (c)).



This provides the first clear indication that adolescents may produce actions which are poorly tailored to the environment and, additionally, indicates what kinds of action are most likely to be affected and why. Examination of the mistrials illustrated in 9.1(b) raises another possibility. In this experiment, there was no significant difference between the number of mistrials in the

High and Low Growth groups. However, the boys in the High Growth group were significantly less likely to overestimate their ability. This suggests that the boys may have been aware of the effects that their recent growth would have on this task and that they could adjust their estimates or performance on the task accordingly. However, when the difficulty of the task was increased by requiring the boys to identify their reaching abilities using long poles, the number of mistrials increased noticeably in the High Growth group only. This pattern of overestimating ability accompanied by high mistrials is very similar to that observed in the 12+13 year old boys in Chapter Two and provides support for the proposal that the boys were acting on an outdated perception-action coupling.

It is of particular interest that previous research of a similar kind to that undertaken in the present thesis has not observed children **under**-estimating their abilities. The only previous studies which observed a large degree of underestimation were by Mark (1987) and Mark et al. (1990). The underestimates of surfaces low enough to sit upon observed in these studies occurred when leg length of observers had been artificially extended by making them walk on 10cm wooden blocks. It is notable that the children who took part in the experiments in the present thesis only underestimated their ability if they were at an age associated with the adolescent growth spurt or if their height measurement had increased in six months previous to testing at a level associated with a growth spurt. This raises an important issue. Mark et al. (1990) proposed that adults are able to adapt their judgements very quickly to their new height when wearing the blocks and that they can make this adjustment without having any experience of attempting the action in question. If this is the case, why would adolescent children have any detectable lag in recalibration following a growth spurt? The likely answer to this question is that any accommodation, whether it be to wearing 10cm blocks, platform shoes, carrying a heavy bag or indeed, reaching with long poles, should by its very nature be a temporary and situationally based one. Waking up next morning and still acting as though leg length is extended would be, ecologically and practically, an invalid response to any such change. There may be a qualitative difference between the calibration changes involved in an intrinsic and permanent change such as growth, or this kind of change may take repeated practice in order to become established. This question is worthy of further investigation.

The exact nature of the changes which accompany the adolescent growth spurt and which may affect perceptuo-motor control and action have been discussed at length. At this stage, it is clear that a combination of factors, including changes in height, muscular strength, limb length and the moments of inertia of the body and limb segments, all necessitate a recalibration, since all affect the relationship between the individual and the environment in which they intend to act. The results presented in chapters two, three, six, seven and eight in particular show that it is the combination of these factors, rather than a change in height alone, which result in children at the age of the growth spurt having problems. In particular, the role of changing moments of inertia and the changes in muscle size and strength which are associated with the growth spurt are implicated, since, in particular, the High Growth children who took part in the reaching with poles experiment found it difficult to maintain balance when this additional increase in rotational moments of inertia had to be taken into account.

A theme which has run throughout this thesis is the relationship between perception and action. The drive to develop and refine the control of action observed in the younger children and the ongoing process of recalibration and accommodation to the environment seen in the older boys indicates that any investigation of the developmental control of movement which does not examine the links between a child's actions and the situation in which they are performed will be incomplete. Clumsiness in adolescence is the result of a time-limited process where the child learns to match a well known and used environment to new adult skills and possibilities for action which are finally revealed by the adolescent growth spurt.

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