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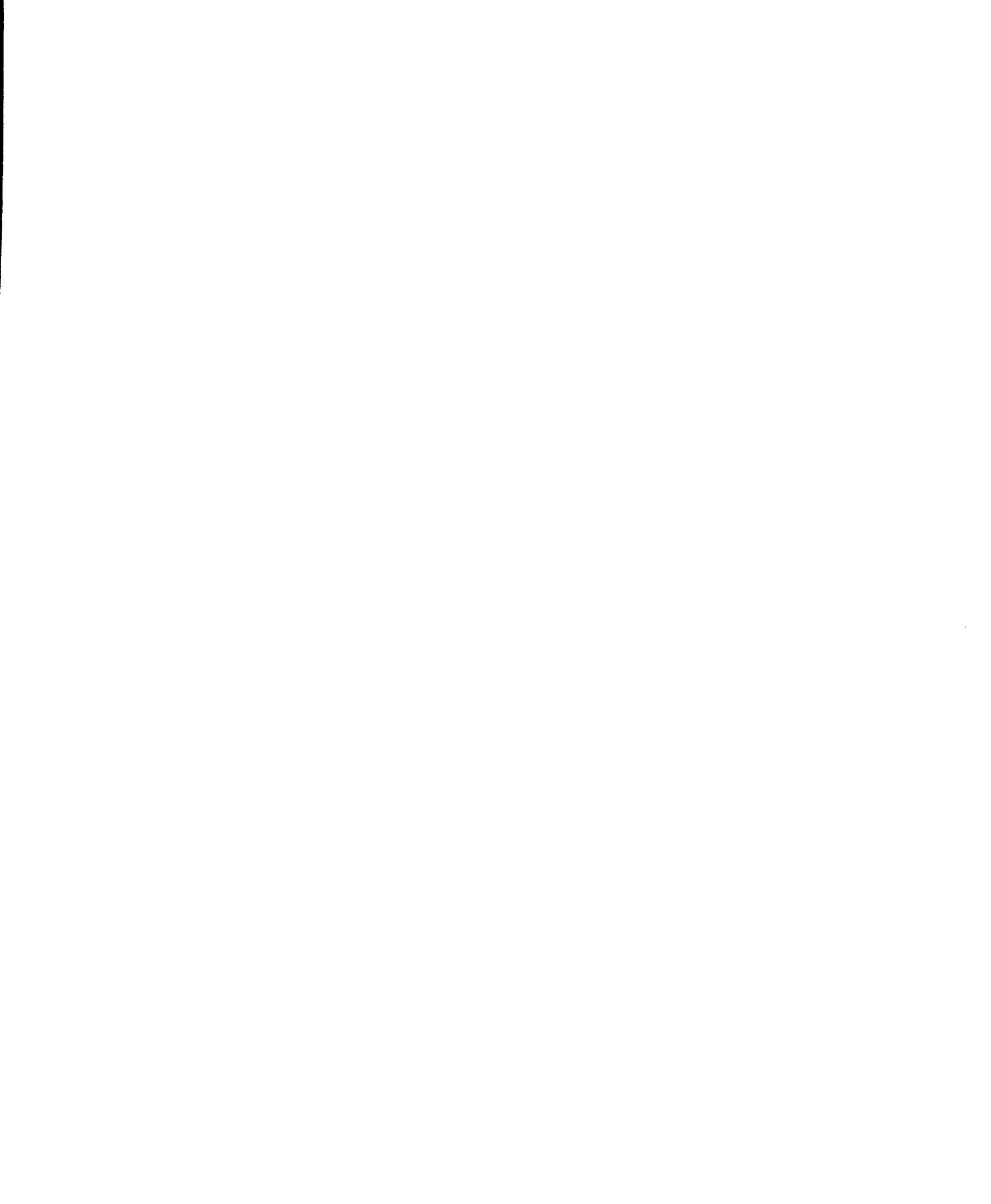
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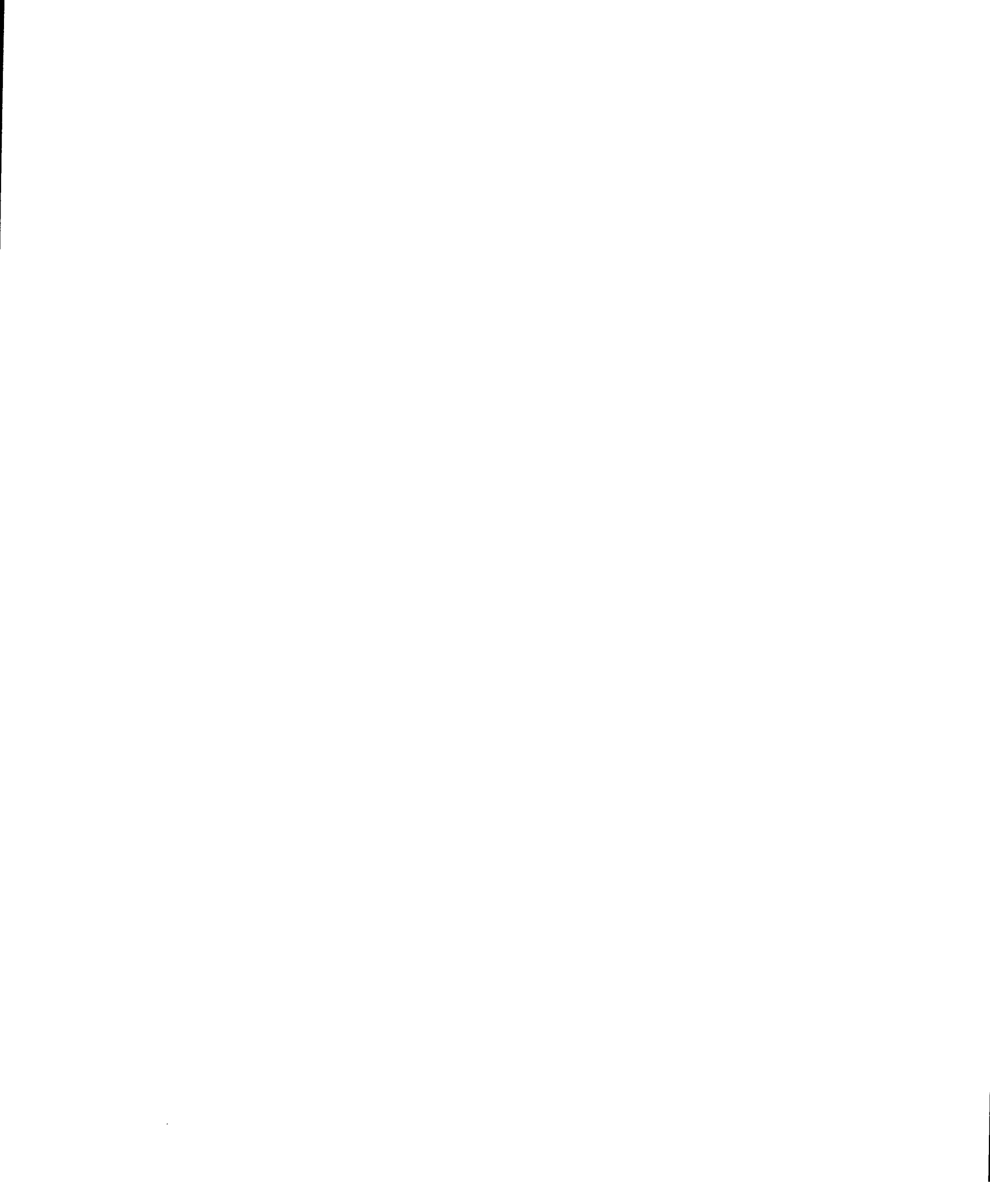
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Feedforward Postural Adjustments Associated with Unilateral Rapid Arm
Motion in Children Aged 4- and 5-years and 10- and 11-years

By

Jennifer McGregor

School of Human Kinetics

Thesis

Submitted in partial fulfillment of the degree Masters in Human Kinetics



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**“Feedforward postural adjustments associated with unilateral
rapid arm motion in children”**

**J.A. McGregor, School of Human Kinetics, University of
Ottawa;**

**Key words: development, balance, anticipatory postural
adjustments, accompaniment postural adjustments and
reaching.**

Abstract

Very little is known of the development of the feedforward postural control mechanism. The purpose of this study was to identify differences in this system between two different stages of development. Two groups of ten children, aged 4- and 5- years old and 10- and 11- years-old took part in this study. Electromyographic (EMG) data from the right anterior deltoid, right and left erector spinae, right and left hamstring muscles and vertical ground reaction force data from the left and right foot as well as the total body, were collected during unilateral rapid forward arm movement about the shoulder in the sagittal plane. EMG and force data were examined for activity 100 ms prior to onset and 70 ms post movement onset. Onset latencies, probability of recruitment and recruitment order were determined for all postural muscles. Onset latencies of changes in the vertical ground reaction forces as well as coefficients of variation were determined for the vertical ground reaction forces. In general, the 4- and 5-year old children demonstrated a similar postural muscle recruitment order as the 10- and 11-year old children. However, the 4- and 5-year old children had a larger proportion of the postural muscles being activated before the movement onset than the 10- and 11-year old children did. The probability of the 4- and 5-year old children recruiting the left erector spinae muscle was significantly less than that of the 10- and 11-

year old children. The 4- and 5-year old children demonstrated greater intra-subject variability about the vertical ground reaction forces than did the 10- and 11-year old children. These data suggest that with development, the feedforward postural used in preparation for a unilateral rapid arm raise becomes increasingly consistent. A shift in the feedforward postural adjustment goal from safety to efficiency is proposed.

Introduction

Postural control has two key elements: orientation and equilibrium (Horak & MacPherson, 1996). Postural orientation consists of locating the body in space with respect to environmental variables such as earth vertical and aligning body parts in a specific orientation with respect to each other. Postural equilibrium, more commonly referred to as balance, deals with the many “destabilising influences on the body: external forces due to gravity and to interactions with the surrounding environment, as well as internal forces generated by the body’s own movement” (Horak & MacPherson, 1996). Regardless of the nature of these forces, they all serve to accelerate the body about its centre of mass. Despite the complex interactions of these destabilising forces we are able to maintain our balance under most conditions with remarkable ease.

Balance requires the use of two types of mechanisms, feedback and feedforward postural adjustments. Without such activity, the incidence of loss of balance and resulting falls would be much greater at all ages amongst the population. Feedback postural adjustments include the reactions based on the afferent visual, vestibular and proprioceptive information that indicate a loss of balance. The feedback postural adjustment generally used to maintain balance during standing consists of leg and trunk postural muscle activation, beginning 70 to 100 ms after an internally or externally induced postural

disturbance has occurred in adults (Cordo & Nashner, 1982) or in children (Sveistrup & Woollacott, 1996). For example, if the support surface that a person is standing on is translated backward, the person will fall forward. A feedback postural adjustment is elicited to regain balance. In this situation the feedback postural adjustment consists of gastrocnemius muscle activity approximately 80 ms post perturbation. This is followed by hamstring and trunk extensor muscle activity at 20 ms delays (Nashner 1977). The postural muscles are activated in a distal-to-proximal pattern in healthy young adults.

The second type of mechanism, feedforward postural adjustments, is defined as anticipating the effect of a movement on posture and co-ordinating the activation of postural adjustments and the intended focal movement to minimise the postural disturbance (Frank & Earl, 1990). For example, prior to and during a rapid forward arm movement about the shoulder joint in the sagittal plane, a feedforward postural adjustment is elicited to counteract the destabilising forces of the voluntary movement. In healthy, young adults, the hamstrings and trunk extensor muscles are activated affecting body position and orientation (Cordo & Nashner 1982). Activation of these postural muscles results in a change in the centre of pressure and the ground reaction forces. Feedforward postural adjustments can be divided into two groups based on their occurrence relative to the postural disturbance (Frank & Earl, 1990). The feedforward postural

adjustments occurring prior to the movement are considered anticipatory adjustments. The feedforward postural adjustments occurring simultaneously with the focal movement are considered accompanying adjustments or accompaniments.

Since voluntary movements may also elicit feedback postural muscle activity, studies of specific mechanisms of posture control and movement must be able to distinguish the muscle activity associated with feedforward postural adjustments from that of the focal movement or feedback postural adjustments. Studies of feedback postural adjustments recorded from both young adults (Cordo & Nashner, 1982) and children (Sveistrup & Woollacott, 1996) following an unexpected movement of the floor have indicated that the postural muscle activity begins 70 to 100 ms after the perturbation. Activity, including postural muscle activity or changes in ground reaction forces associated with voluntary movement is generally considered accompaniment activity if it occurs between the movement onset and up until 70 ms after the movement onset (Frank & Earl, 1990). The anticipatory period is limited to 100 ms before movement onset to eliminate the possibility of recording muscle activity or movement associated with random events such as voluntary shifts in position.

Feedforward Postural Adjustments- the Young Adult Pattern

The majority of studies on feedforward postural control focus on postural adjustments associated with rapid arm movement. Bouisset and Zattara (1981) reported a forward and upward acceleration of the body's centre of gravity, occurring just before the onset of arm elevation. This preparation would directly oppose the movement of the body that would result from the arm movement. Feedforward postural adjustments "create in a body a movement whose forces of inertia will, when the time comes, balance the inertia forces due to the movement of the mobile limb, which tend to disturb the postural equilibrium" (Bouisset & Zattara, 1987). Given that more rapid movements generate larger forces, a rapid arm movement will create greater postural disturbances than a slow one (Freidli, Hallet & Simon, 1984).

A recent study on postural adjustments accompanying fast pointing movements in standing, sitting and lying adults, reported that standing offered the greatest opportunity to observe anticipatory behaviour (Van der Fits, Klip, VanEyckern & Hadders-Algra, 1998). Maintaining the centre of mass within the base of stability requires a larger effort when the support surface is small (Massion, 1992). Previous research has suggested the need for anticipatory postural muscle activity may be limited to situations where loss of balance is more probable (Hay & Redon 1999).

The pattern of arm muscle activity during a rapid arm movement is distinctive with a tri-phasic pattern of sequential bursts of activity in the agonist, the antagonist and the agonist muscles (Angel, 1975; Freund & Budinggen, 1978). Hallet and colleagues (Hallet & Marsden, 1979; Hallet, Shahani & Young, 1975) argue that the activity in the agonist and antagonist arm muscles during a rapid arm movement is pre-programmed since the duration of the first agonist burst increases with movement amplitude. A similar alternating burst pattern in antagonist pairs of leg and trunk muscles, comparable to the tri-phasic pattern in the arm muscles, has also been noted. This suggests that electromyographic (EMG) activity in the postural muscles is also pre-programmed (Hallet & Marsden, 1979; Hallet, Shahani & Young, 1975). In a rapid-reach paradigm, activity in the postural muscles precedes activity in the anterior deltoid muscle in a fixed sequence. Specifically, the leg muscles are activated earlier than the trunk muscles. Since feedforward postural adjustments begin before and are specific to the focal movement as well as the postural set, for example initial body position and the attention being given to the task, the argument for pre-programmed postural activity is strong. However, it is unclear when during the development of posture control this programme is developed or when the ability to use pre-programmed postural adjustments becomes available.

Development of Feedforward Postural Control

In an early study of the development of feedforward postural control of upright stance, children were asked to rise from a flat-footed stance to an "on tiptoe" position (Haas, Deiner, Rapp & Dichgans 1989). Children between the ages of 4 and 6 years demonstrated feedforward postural adjustments similar to those recorded in school-aged children, between 8 and 14 years of age. The feedforward postural adjustments consisted of a forward shift in the centre pressure prior to the lifting of the heels. Children under the age of four were unable to demonstrate the task during the experimental sessions. Thus, the data seemed to suggest that feedforward postural adjustments developed as late as four years of age. However, these researchers commented that infants demonstrated feedforward behaviour while sitting and reaching for an object or while crawling or walking although no data were presented to support this statement. The authors stated that the feedforward behaviour demonstrated by the infants apparently appears shortly after they are able to maintain a sitting, crawling or upright stance position. If feedforward postural adjustments are present in children under four years of age, it is possible that the task, rise to tiptoe, is inappropriate for studying the development of these adjustments. One possibility is that children under the age of four have not yet mastered the motor skill of rising to an "on tiptoes" position. Another possibility is that the children have

acquired the motor skill but lack the ability to focus their attention in a complex task paradigm.

When a different paradigm was used to study feedforward postural adjustments in children aged four to fourteen years (Riach & Hayes, 1990), feedforward postural adjustments were identified, even in the youngest children. However the postural adjustments recorded in the youngest were neither consistently present nor when present, consistent. The task used was a unilateral rapid arm motion and feedforward postural adjustments were identified as shifts in the displacement of the centre of pressure (COP) in the anterior-posterior and lateral directions. The feedforward postural adjustments recorded were posterior shifts in the COP prior to the onset of arm acceleration. Two test procedures were used; one was a simple reaction time task while the second task involved a more complex choice reaction time task with a variable foreperiod. The results of children who completed the simple reaction time task were compared to the results of children of the same age who completed the complex task. All children, regardless of age, were less likely to use anticipatory postural adjustments in a task involving a high degree of uncertainty than in the simple reaction time task (Riach & Hayes, 1990). It is possible that the complex reaction time tasks require a greater decision making period, thereby requiring the children to focus on the proper focal movement rather than on incorporating the appropriate postural

preparation with the correct focal movement. Since complicated tasks resulted in fewer and more variable postural adjustments, studies of the emergence and development of feedforward postural adjustments should incorporate a simple task in order to increase the likelihood of eliciting feedforward postural adjustments.

Hay and Redon (1999) compared the postural adjustments associated with self-initiated disturbances to those associated with externally initiated postural disturbances by measuring the displacement of the COP. The children were asked to hold a weight (5% of body mass). The child would either drop the weight (self-initiated postural disturbance) or an experimenter would unexpectedly remove the weight from the child (externally initiated postural disturbance). The amplitude of self-initiated disturbance decreased between the three-to-five year old subjects and the six-to-eight year olds and increased again in the 9- to 10-year-olds and adults (Hay & Redon, 1999). This decrease in amplitude could be due to a strategy focussing on remaining as still as possible as a means of safely controlling the postural perturbation associated with this focal movement. It is possible that once the children have acquired the skill of anticipating the effect of the self-initiated disturbance by 9- to 10-years of age, they become more confident in their ability to remain stable therefore allowing greater displacement amplitudes in the resulting postural disturbance. The reduction of the amplitude of the

resulting postural disturbance between the youngest group and the 6- to 8-year olds suggests that these children are indeed attempting to remain completely still. There were no significant differences in displacement amplitudes between the two older groups.

It has been established that feedforward postural adjustments are task specific and likely pre-programmed. Feedforward postural adjustments have been elicited in tiptoe standing and rapid arm raises in children as young as four years of age as evidenced by centre of pressure displacements. However, only limited data on centre of pressure changes have been reported regarding the postural muscle activity involved in feedforward postural adjustments or how that muscle activity changes with development. However the developmental progression of feedback postural control has demonstrated increased variability in the 4-to5-yearolds, an increase in the number of postural muscles incorporated in the response with decreased muscle onset latencies

This study focused on the differences in feedforward postural muscle activity occurring in children aged 4- to 5-years and 10- to 11-years of age. Specifically activity of the right and left hamstrings and the right and left erector spinae muscles, as well as changes in the vertical ground reaction forces associated with a rapid forward arm raise, were studied. Feedback postural control research has reported a transitional period occurs at approximately 6 years of age. During this

transitional period the children are unable to resolve conflicting sensory information, meanwhile 10-11-years olds are considered to demonstrate a mature pattern. The age groups in the current study were selected as pre transitional and post transitional of the feedback development.

Hypotheses

1. The variability about the mean of ground reaction forces as quantified by the coefficient of variation will be greater in the younger children than in the 10- and 11-year old children.
2. The 10- and 11-year old children will demonstrate a greater probability of postural accompaniments than anticipatory postural adjustments. The contrary will apply for the 4-and 5-year old children.
3. There will be a reduction in the onset latencies of the postural muscles with age.
4. There will be a reduction in the latencies of changes in the vertical ground reaction forces with age.
5. There will be an increase in the probability of recording a change in the vertical ground reaction forces with age.

Methodology

Subjects and Recruitment

Two groups of ten children, aged 4- and 5-year-olds (mean 5.2 ± 0.6 years) and 10- and 11-year-olds (mean 11.2 ± 0.6 years), took part in this study. The young group consisted of eight girls and two boys, while the old group had six girls and four boys.

Subjects were recruited from the community by word of mouth. Informed consent was obtained from both the child and their legal guardian prior to the child being instrumented with the testing equipment.

Instrumentation and Data Acquisition

Pre-amplified surface electrodes (Neuromuscular Research Center, Boston, Massachusetts) were used to record activity of the right anterior deltoid muscle, the left and right erector spinae muscles at the lumbar level, and the left and right hamstring muscles. A ground electrode was attached over the iliac crest. An accelerometer (Entran model EGAX-25) attached to the right wrist of the child was used to indicate movement onset. Finally, the child was standing on two force platforms (AMTI, model OR6-5) embedded in the floor, one under each foot. Foot positions were indicated by footprints placed 10 cm apart to ensure that a consistent stance position was used. The force platform

system was zeroed while the child was standing on the platforms, thereby normalising the data by weight. Prior to instrumentation, children executed two to three practice trials to assure their comfort with the task. Once instrumented, two to three more practice trials were completed to ensure that the cables from the electrodes and the accelerometer would not interfere with either the movement or comfort of the child.

Force, accelerometer and EMG data were collected at 500 Hz using APAS (Ariel Performance Acquisition System, Trabuco Canyon, California) software.

Task

The children were in bare feet and instructed to stand as still as possible with both arms at their sides. They were told to reach with their right hand as quickly as possible when they heard the command "GO" and to point at an object located 1.5 m in front of the right shoulder at shoulder height (Figure 1). They remained in the final position with their arm parallel to the floor in the sagittal plane until told to relax, about 2 seconds. Each child completed a minimum of ten reaches with their right hand.

Data Processing

Electromyography

EMG data were baseline zeroed, full wave rectified and then examined for muscle burst activity in each of the five muscles using the BIOPROC (Lamontagne, Bradley & Lemaire, 1989) software package. Two separate analyses were performed to determine muscle onset latencies for each muscle. For the first analysis, the change in the accelerometer signal corresponding to the onset of wrist movement for reaching was used to identify the start of the focal movement (Lee, Buchannan & Rogers, 1987). A period of 170 ms was examined for activity; 100 ms prior to and 70 ms post movement onset as determined by the accelerometer. For the second analysis, the time of onset of activity recorded from the anterior deltoid muscle was used to identify the start of the focal movement (Aruin & Latash, 1995), therefore 100 ms prior to focal muscle onset and 70 ms post focal muscle onset were examined. A previous study reported that the difference in focal muscle onset time and the onset of movement could be as large as 50 ms (Freidli, Hallet & Simon, 1984). Therefore, if postural muscles were working together as a synergy, postural muscle onsets should be calculated relative to the focal muscle onset. As it has not been established that postural muscles do indeed function as a synergy, it was considered prudent to examine both points in time as an onset.

A burst of muscle activity was defined as activity two standard deviations above baseline lasting a minimum of 50 ms (Figure 2)(Sveistrup & Woollacott, 1996). For both analyses, the postural muscles were examined to determine only the first burst of activity. Therefore, if a postural muscle was activated in the anticipatory period it was not coded as active in the accompaniment period.

The onset latencies of each of the postural muscles relative to the onset of arm movement and the onset of focal muscle activity were determined separately for all trials for each child. The mean onset latency for each postural muscle was calculated based on data from between 10 to 15 individual trials for each child. The mean data were used to represent muscle onset latencies for that child. The means for each child were then used in the calculation of the group data. Separate means were calculated for activity relative to focal muscle and movement onset. For both analyses, a separate mean was calculated for the anticipatory period, the accompaniment period and the entire feedforward period, which consists of the anticipatory period and the accompaniment period.

The probability of recruiting a postural muscle within the feedforward window was determined, relative to arm movement onset and focal muscle onset, for each child for the anticipatory, accompaniment and feedforward periods. The probability of activity was calculated for each muscle by dividing the number of trials where a

given postural muscle was activated by the total number of trials analysed for that child. For example, if a child completed 10 trials and used their right erector spinae muscle in six trials, (4 anticipatory and 2 accompaniment) the probability of feedforward activity would be 60%. The probability of anticipatory or accompaniment activity would be 40% and 20%, respectively.

Ground Reaction Forces

Vertical ground reaction forces were analysed rather than centre of pressure displacement. Previous work has shown that changes in the vertical ground reaction force are more reliable indicators of changes in position than are changes in the centre of pressure (Goldie, Bach & Evans, 1989). The vertical ground reaction force (GRF) data were aligned according to arm movement onset as determined by the accelerometer. These data were then examined using the BIOPROC software package. The magnitude of the GRF varied between children. To allow for this inter subject variation, the trials for each child were plotted on the same vertical axis (Figure 3) and then each trial was coded for feedforward postural adjustments. This ensured that noise or other artefacts were not accidentally coded as a change in the GRF. Feedforward postural adjustments were identified as changes in the GRF from baseline. Again a period of 170 ms was examined for shifts in activity, 100 ms prior to movement onset and 70 ms post movement

onset. The vertical GRF data were analysed for onset latencies of the changes in GRF (right foot, left foot and summed for total body representation).

Between 10 and 15 trials per child were used to calculate the ensemble average of the GRF during the feedforward period. The

$$CV = \frac{\sqrt{\frac{1}{N} \sum_{i=1}^N \sigma_i^2}}{\frac{1}{N} \sum_{i=1}^N |X_i|}$$

Winter, 1984

variability between trials for each child was quantified using the coefficient of variation (CoV), which is a measure of variability about the mean of ensemble averaged curves (Winter 1984). For example, a child whose GRFs were very variable amongst trials would have a high coefficient of variation, whereas a child whose GRFs were consistent amongst trials would have a low coefficient of variation (see Figure 4). The intra-subject CoV was calculated separately for anticipatory period, the accompaniment period as well as the full 170 ms feedforward period to allow comparison between groups of intra-subject variability for each respective time period. An alternate equation for the CoV is presented in Annex 1. While the results of this alternate equation vary in absolute differences than those presented, the relative differences are the same, the trends these data present are unchanged.

Finally, the inter-subject variability between groups was determined. In this case, an inter-subject CoV was calculated for each

group from the ensemble average of the force curves (right foot, left foot and total body) for each child in the group.

Statistical Analysis

Analyses of variance (ANOVA) were used to identify statistically significant differences between the young and old groups in: a) postural muscle onset latencies relative to movement onset; b) postural muscle onset latencies relative to the onset of the focal muscle; c) timing of changes in the vertical GRF relative to the change in accelerometer signal; and d) the intra-subject CoV.

Chi-square tests were used to determine differences between the young and old groups in: a) probability of recording activity in a postural muscle relative to movement onset; b) probability of recording postural muscle activity relative to the focal muscle onset; and c) probability of recording a change in the vertical GRF from the left foot, right foot or total body. Probability data were analysed for anticipatory, accompaniment and feedforward periods.

For findings to be considered statistically significant, a p value less than or equal to 0.05 was required.

A post-hoc power analysis was conducted on the muscle onset latency data.

Results

The results are presented in three sections: 1) muscle onset latencies and changes in ground reaction force latencies, 2) probability of recording feedforward postural adjustments and 3) variability of the feedforward postural adjustments recorded. A table of subject characteristics can be found in Annex 2. The force and EMG data are presented together within each section. All statistical tests that yielded a p value of less than 0.1 are indicated in the figures to allow some comparison. The significance of the results of the statistical analyses may be limited by the sample size. The results of this study indicate trends toward certain behaviours rather than statistically significant differences between age groups.

Latencies

Postural muscle onset latencies relative to movement onset are plotted for both age groups (Figures 5a-c). Focal muscle onset latency is plotted in Figure 5a but does not appear in the other two graphs since it is always activated prior to movement onset and thus within the anticipatory period. To include it in the feedforward graph would be to duplicate what is shown in the anticipatory period. Focal muscle activity occurred approximately 40 ms prior to movement onset in both groups of children. There were no significant differences between groups in anticipatory, accompaniment or feedforward postural muscle

onset latencies. However it should be noted that the right erector spinae muscles of the 4- and 5-year old children were recruited earlier in the anticipatory period by the 4- and 5-year old children ($p=0.059$) and during the accompaniment period this muscle was recruited sooner by the 4- and 5-year old children than in the 10- and 11-year old children ($p=0.051$).

A separate analysis of postural muscle onset latencies relative to focal muscle onset latency resulted in slightly different group differences. Specifically, in the anticipatory period (Figure 6a), the onset latencies of the right erector spinae muscles were significantly different between groups, with the younger children exhibiting a statistically significantly earlier onset than in the 10- and 11-year old children. Although not statistically significant, the rest of the postural muscles were also activated earlier in the 4- and 5-year old children in the 10- and 11-year old children during the anticipatory period, with exception of the right hamstring muscle. In the accompaniment period (Figure 6b), the results indicate a trend, all the postural muscles monitored were activated later in the 4- and 5- year old children than in the 10- and 11-year old children.

When the sequence of postural muscle recruitment was determined, an interesting pattern emerged. When the order of recruitment is plotted relative to the focal muscle onset (Figures 7a & b), the mean sequence of muscle activation was identical between

groups. The right hamstring muscles were activated followed by the left erector spinae then right erector spinae followed by the left hamstring muscles. The difference in the activation sequence between groups lies in which period, either anticipatory or accompaniment, the postural muscle is activated in. On average, in the 4- and 5-year old children, the right hamstring, left erector spinae and right erector spinae muscles were activated in the anticipatory period and only the left hamstring muscle was activated in the accompaniment period. In the 10- and 11-year old children, the average was for only the right hamstrings to be activated in the anticipatory period with the left erector spinae, right erector spinae and left hamstring muscles activated in the accompaniment period.

Timing of the feedforward postural adjustments as indicated by changes in the GRF traces are plotted for the right foot, left foot and total body during the three time periods for both groups (Figures 8a-c). Although the onset latencies of changes in the vertical ground reaction forces of the young group were on average, earlier in the anticipatory period as well as later in the accompaniment period, no significant differences between groups were identified.

To summarise, there was a tendency for the 4- and 5-year old children to activate the left hamstrings right erector spinae and left erector spinae muscles earlier than the 10- and 11-year old children when activated in the anticipatory period. In the accompaniment period

the younger children activated the postural muscles later than did the 10- and 11-year old children. The mean sequence of muscle activation was the same for both groups of children: right hamstring, left erector spinae, right erector spinae and finally left hamstrings. However there was a shift from activation of the majority of postural muscles in the anticipatory period to the accompaniment period with development. Not surprisingly, the GRF data demonstrated the same trend as the postural muscle activation latencies.

Probability

The probability of recording postural muscle activity is illustrated for each muscle during each time period in figures 9 and 10. Analysis of the probability of recording postural muscle activity relative to movement onset revealed a significant difference between groups in the probability of left erector spinae muscle activation (Figures 9a-c). There was a greater probability that this muscle would not be recruited by the younger children (Figure 9c).

When the focal muscle onset was used as the zero point (Figures 10a-c), the probability of recording left erector spinae muscle activity during the accompaniment period was significantly different between groups. The probability of recording activity from this muscle was much higher in the 10- and 11-year old children (Figure 10b).

The probabilities of recording a shift in the GRF during either the anticipatory or accompaniment period were compared. No significant differences were found between groups (Figure 11 a-c). It should be noted that in the vertical GRF data, probability of a shift in left foot vertical GRF plus probability of a shift in right foot vertical GRF does not equal the probability of shift in total body vertical GRF. This is due to changes in vertical GRF occurring in the left and right foot during the same time period for an individual trial.

To summarise, the probability data indicated that the 4- and 5-year old children were most likely not to recruit the left erector spinae muscle. However, when the 4- and 5-year old children did recruit this muscle during the accompaniment period, the 10- and 11-year old children demonstrated a significantly greater probability of recruitment. The GRFs data revealed no differences in the probability of recording a shift between age groups, nor any difference in the timing of these shifts.

Variability

The intra-subject coefficient of variation is a measure of the variability in the vertical ground reaction forces between trials for each child. A separate coefficient of variation (CoV) was determined for the anticipatory, accompaniment and feedforward time periods. The coefficients calculated for each child were averaged to determine the

mean coefficient of variation for each age group. The mean CoV for the total body vertical ground reaction forces are plotted. Although there was a tendency for the younger children to be more variable in their patterns of GRF changes than the 10- and 11-year old children, the differences were not statistically significant (Figure 12).

The inter-subject coefficient of variation is a measure of the variability between children within an age group. The mean vertical ground reaction force data for each child was used to calculate the CoV for each age group. The inter-subject CoV's were similar between groups for the right and left feet and for the combined total body force data. Only the data from the total body are shown (Figure 13). The 4- and 5-year old children demonstrated slightly greater inter-subject variability in the anticipatory period than the 10- and 11-year old children. Meanwhile, the 10- and 11-year old children demonstrated slightly greater inter-subject variability than the younger children in the accompaniment period as well for the total feedforward period.

To further illustrate the differences in variability, the total body GRF data from 15 trials for three children in each age group are plotted (Figures 14a-b). The GRF traces recorded from the younger and 10- and 11-year old children are shown in the first and second set of traces respectively. Note that the younger children appear not to shift their vertical GRF nearly as often as the children in the older group. One possible explanation is that the children are attempting to remain as

still as possible. In contrast, the 10- and 11-year old children demonstrated greater changes in their vertical GRF both in the number of trials when a change occurred as well as in the magnitude of these changes.

To summarise, the younger children demonstrated a trend of greater intra-subject variability than the 10- and 11-year old children, while the opposite held true for inter-subject variability in the accompaniment period as well as the overall feedforward period.

Discussion

It has been proposed that as children develop, their limits of tolerance to imbalance increase as a result of their acquiring greater mastery of postural control (Hay & Redon, 1999). Rather than maintaining equilibrium by limiting movement, postural control becomes more dynamic. Thus, the body is allowed to move more freely within broader limits of stability. Frank and Earl (1990) proposed a representation of posture control (Figure 15) that holds safety and efficiency of postural control as diametrically opposed. Safety was interpreted as trying to limit the amount of postural disturbance produced by a voluntary movement. In contrast, allowing the body to move freely, actively anticipating the amount of disturbance that would accompany the voluntary movement and manoeuvring this disturbance to ones benefit could be interpreted as more efficient (Woollacott &

Manchester, 1993). Anticipatory postural adjustments have a greater component of safety than accompaniments. Therefore, accompaniments were considered less safe but more efficient. This model proposes that an increase in efficiency results in a decrease in safety.

Based on the premise that 4- and 5-year old children respond earlier to self-initiated postural disturbances and have the goal of remaining completely stable, there would be greater focus on the postural aspect associated with a focal movement rather than the focal movement itself. Especially, since it has been shown that younger children have a lower tolerance limit for imbalance. Therefore an earlier postural preparation with the intent to remain still while completing the focal movement would be the safest approach to completing the desired task. With development, the tolerance limits to imbalance increase as the effectiveness of posture control increases. This allows greater movement of the body accompanying the focal task with out causing instability. It seems reasonable that remaining almost perfectly still would require greater effort than allowing the body to move freely, therefore justifying the use of the term efficient.

Although many of the differences between groups were not statistically significant, it is quite possible that this is due to the small sample size. Samples were not gender matched and the small size precludes any analysis of gender differences. The results demonstrate a

trend of decreasing intra-subject variability of the feedforward postural adjustments with increasing age.

Timing of Postural Adjustments

Previous studies of feedback postural responses have shown that with development there is a reduction in the onset latency of postural muscles (Shumway-Cook & Woollacott, 1982). Sveistrup and Woollacott (1996) identified a trend in infants towards reduction in muscle onset latency but only in the distal postural muscles. Cordo and Nashner (1982) hypothesised that the feedback postural response mechanism is the same mechanism used in the feedforward postural control, but that it is used in a different context. It is likely that if they are the same mechanism, they will share developmental patterns. In fact, Van der Fits et al. (1999) reported an age-related increase in the number of postural muscles incorporated into a feedforward postural adjustment in infants as previously reported for the development of feedback postural control in infants (Sveistrup & Woollacott, 1996). With the exception of the right hamstring muscle, all postural muscles recruited in the anticipatory period were activated earlier by the younger children. It is possible that a decrease in onset latency relative to the focal muscle onset is also occurring in development of feedforward postural control. If this is indeed the case, one would expect that in the accompaniment period, the postural

muscles onsets would be closer to the focal movement in the 10- and 11-year old children, as was demonstrated (Figure 6b).

The adult pattern of feedforward postural adjustments recorded for a similar task begins with activity in the right hamstring muscle (Woollacott & Manchester, 1993). In the 4- and 5-year old children, the right hamstring muscle is activated only slightly ahead of the right erector spinae muscle rather than the average 40 ms plus between onset of right hamstring and right erector spinae muscles recorded in the 10- and 11-year old children. In adult subjects, the right hamstring muscles were recruited 101 ms (+/- 77 ms) prior to the right erector spinae muscle (Lee et al., 1987). This demonstrates a trend, increasing the length of time between right hamstring onset and right erector spinae muscles with development.

Lee et al. (1987) noted that in adult subjects, low velocities of the unilateral arm movement resulted in extreme increases in the variability of postural muscle onset latency when compared to results obtained from rapid arm movements. In the current study, some of the children in the young group executed slower arm reaching movements than their older counterparts despite receiving identical instructions to point as fast as possible. Upon qualitative inspection, no differences could be found between the postural muscle activity of the 4- and 5-year old children who reached slower than the 4- and 5-year old

children who reached rapidly. Thus it was concluded that differences in muscle onset latency variability were not due to arm reach velocity.

Alternatively, the differences recorded between groups may reflect a shift in priority from safe to efficient control (Figure 15). Upon examination of the sequence of postural muscle activation relative to the focal muscle onset (Figure 7b), one difference between age groups becomes quite clear. Both groups of children are using the same sequence of postural muscle activation, but the younger group used all but the left hamstrings in the anticipatory period while the older group used all but the right hamstrings in the accompaniment period. This observation supports the hypothesis that the younger subjects use a strategy focussed on safety rather than efficiency since the majority of feedforward postural muscle activity occurs in the anticipatory period. Meanwhile the 10- and 11-year old children with their increased tolerance to imbalance appear to use a strategy more focussed on efficiency. Young adult data collected (Casimero & Sveistrup, unpublished data) demonstrated a continuation of this trend away from safety towards efficiency.

Organisation of Postural Adjustments

There is been evidence from previous studies indicating that feedforward postural adjustments are organised in parallel with the focal movement (Brown & Frank, 1987). It is possible that one

characteristic of development is the integration of these two commands. The current data show that relative to focal muscle onset, the pattern of activation of the postural muscles is identical between groups. However, one difference in the muscle recruitment pattern is the placement of the focal muscle within the sequence. It is possible that this difference is a reflection of the change in the integration of the focal movement and the feedforward postural adjustment.

This would appear to indicate that the sequence of postural muscles is established before the timing is optimised for different goals at different ages. Such is the case in the development of feedback postural control. In a longitudinal study by Sveistrup and Woollacott (1996), it was reported that as infants developed a feedback postural control mechanism for externally induced postural disturbances they incorporated more muscles into the postural response and that the proportion of trials with postural muscle activity increased with development. It is possible that the same is true of feedforward postural development. This feedforward development may occur later in life, in the 4- and 5- year olds for the feedforward postural adjustment associated with rapid unilateral arm motion during standing. It is also possible that the 4-to 6-year-olds are in a transition period as suggested by Hay and Redon (1999).

Variability of Postural Adjustments

The higher CoV intra-subject variability displayed by the

children in the young group indicates that they did not consistently reproduce the same vertical GRF changes from trial to trial. Riach and Hayes (1990) reported similar inconsistency with feedforward shifts in the centre of the younger children were present but inconsistent. The inconsistent postural responses recorded in the 4- and 5-year old children suggested an inability to integrate the feedforward postural adjustment with the focal movement (Riach & Hayes, 1990).

The inter-subject CoV results can be interpreted in two different ways. The first is that the younger children are all using the same strategy and therefore there is very little variation within the young group. The second interpretation is that they 4- and 5-year old children are not moving as a result of feedforward postural adjustments. Upon qualitative examination of the force traces, no patterns, much less a common pattern is evident. Therefore, this would indicate that the children in the younger group did not perform a feedforward postural adjustment by changing their vertical GRF. This finding is based on the overall lower group inter-subject CoV for the feedforward period and the infrequency of actual shifts in the younger children's GRF.

The finding of shorter postural muscle onset latencies in the anticipatory and accompaniment periods in the 10- and 11-year old children are similar to those reported in the development of feedback postural control in infants (Sveistrup and Woollacott, 1996), who reported a trend in the reduction of distal postural muscle onset latency

in the feedback postural response. Sveistrup and Woollacott suggested that this indicated a development of the posture control mechanism.

Sveistrup and Woollacott (1996) and Van der Fits et al. (1999) reported that with development, a greater number of muscles were incorporated into the postural response.

Conclusion

This study demonstrates that feedforward postural adjustments appear to follow many of the same developmental trends as feedback postural control. For example, with age we see a trend in the increase of the number of postural muscle incorporated into a feedforward postural adjustment. In addition, with development we see a trend in the reduction of onset latencies of accompaniment postural adjustments. The findings that the 4- and 5-year old children use the same postural muscle sequence as the older, but with less consistency is also typical of feedback postural development.

It is possible that the lack of statistical significant differences between groups is due to small sample size. The post-hoc power analysis, results shown in table 8, support this. This analysis indicates for a power level of 0.95 with a medium effect size, and an alpha level of .05, 105 subjects would be required in each age group.. However, trends in the data do support the hypotheses presented.

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Annex 1. Subject Characteristics

Subject	Age	Sex	Height	Foot Length	
				Right	Left
1	5.17	female	114.5	12.8	12.8
2	5.34	female	116	13	13
3	5.46	female	113	11	11
4	4.50	male	106.5	11.2	11.2
5	5.52	female	109	11	11
6	4.55	male	107	11	11
7	4.00	female	109	13	12.5
8	5.25	female	110	11.5	11.5
9	5.83	female	111	12	11.5
10	5.75	female	122	12.4	12.2
11	11.17	male	137	16	16
12	10.83	female	144	13	13
13	11.67	female	144	15	15
14	10.01	male	137	15.5	15.5
15	10.42	female	137	13.5	13.3
16	11.67	male	152	16	16
17	10.83	female	144	15	15
18	11.92	male	158	17	17
19	11.33	female	142	13.3	13
20	11.25	female	141	15.5	15.3

Age is indicated in years. All other measurements are in centimetres.

Annex 2. Alternate Coefficient of Variation Equation

$$CV = (\sqrt{(\Sigma(\sigma^2))/n})/(\sqrt{(\Sigma(\chi^2))/n}) \cdot 100$$

Giroux & Lamontagne, 1992

Figure Captions

Figure 1.

a) Right side view of the final position. The curved line with arrows indicate arm trajectory. b) An overhead view of the subject in the final position. The black circle represents the top of the child's head, the two squares in the background are the force platforms the child is standing on, and the black bar is the child's arm in the final position.

Figure 2.

An example of full wave rectified EMG data and non-rectified accelerometer data for a three-second period. From top to bottom, traces represent activity in the right anterior deltoid, right erector spinae, right hamstring, left erector spinae, the left hamstrings and the accelerometer trace. Arrows indicate onsets in muscle activity or movement onset from the accelerometer data. These data are from one trial recorded from an eleven-year-old subject.

Figure 3.

An example of seven trials of total body vertical ground reaction force traces recorded from an eleven-year-old subject, the same subject as the previous figure. A one-second window is shown. The first solid vertical line represents the beginning of the anticipatory period, the dashed vertical line represents movement onset and the second solid

vertical line represents the end of the accompaniment period. Arrows represent the point in time that a change occurred in the vertical ground reaction force. Note the consistency with which this child changed his vertical ground reaction force in the anticipatory and accompaniment periods.

Figure 4.

The mean total body vertical ground reaction force curves (\pm stdev) for two children are plotted to demonstrate the contrasts in coefficients of variation. The first vertical line indicates the beginning of the anticipatory period; the second vertical line indicates movement onset while the third vertical line indicates the end of the accompaniment period. A narrower band formed by the two standard deviation curves about the mean would result in a smaller coefficient of variation. The curves labelled "A" are from a five-year-old boy with a coefficient of variation of 3.3 for the entire feedforward period. The curves labelled "B" are from an eleven-year-old girl with a coefficient of variation of 0.3 for the feedforward period. Note how tightly the standard deviation curves hug the mean curve especially in the feedforward period for the eleven-year-old.

Figure 5

The figures represent muscle onset latencies relative to movement onset in the young and old groups of children. No significant differences were found. However, all p values $p \leq 0.1$ are indicated on figures. Onset latencies (mean +/- stdev) of the focal muscle, anterior deltoid and four postural muscles are shown for a) the anticipatory window, b) the accompaniment window, and c) the entire feedforward period (anticipatory and accompaniment).

Figure 6.

The figures represent postural muscle onset latency relative to focal muscle onset in the young and old groups of children. Onset latencies (mean +/- stdev) of the four postural muscles are shown for the a) anticipatory period, b) the accompaniment period, and c) the entire feedforward period. Note the statistically significant difference between groups of the right erector spinae muscle latency ($p = .02$) in the anticipatory period. Also note that all values where $p \leq 0.1$ are indicated on figures for comparison.

Figure 7.

A scatter plot is used in a rather unconventional manner to demonstrate the sequence of postural muscle activation. The temporal sequences of

postural muscle activation relative to focal muscle onsets are illustrated for a) the 4- and 5-year old children and b) the 10- and 11-year old children. The vertical line indicates the onset of the focal muscle, 100 ms prior to focal muscle onset and 70 ms post focal muscle onset are shown. For both a & b the top series of muscle activation represent the mean group data while the subsequent series show the activation sequences of the individuals in that group. In figure a, note that 6 out of 10 the children recruit only 3 of the postural muscle while the 10- and 11-year old children, figure b, only 1 child recruits only 3 of the postural muscles. The other difference between the two age groups of note is the proportion of muscle activation, which occur before and after focal muscle onset. The younger children clearly demonstrate a propensity for activating the postural muscles in the anticipatory period rather than the accompaniment period. In contrast the 10- and 11-year old children activated the majority of their postural muscles in the accompaniment period.

Figure 8.

Timing of the feedforward postural adjustments in the vertical ground reaction forces recorded for the right foot, left foot, and total body for the a) anticipatory period b) the accompaniment period and c) the entire feedforward period. The mean latencies (+/- stdev) are shown for the

young and old groups. No statistically significant differences between groups were found.

Figure 9.

The probabilities of muscle activation relative to the movement onset are shown for the young and old groups. The probabilities of muscle activation during the a) anticipatory window and b) accompaniment window are shown. The probability of not recording muscle activation is shown in c. Note the greater probability for the younger children to not incorporate the left erector spinae muscle as part of their postural control strategy.

Figure 10.

The probabilities of postural muscle activation relative to the focal muscle onset are shown for the young and old groups, for the a) anticipatory period b) accompaniment period. The probability of not recording muscle activation is shown in c. Note the greater probability the 4- and 5-year old children did not recruit the left erector spinae muscle while the 10- and 11-year old children demonstrated a greater probability of recruiting this muscle in the accompaniment period.

Figure 11.

The probability of a feedforward postural adjustment occurring in the vertical ground reaction force for each period relative to movement onset is shown for a) the left foot b) the right foot and c) the total body, for both groups of children. The 4- and 5-year old children are shown on the left-hand side in the lighter shade and the old children to the right in the darker shade.

Figure 12.

The mean (+ stdev) intra-subject coefficients of variations of the GRFs are plotted for both groups of children for the anticipatory, accompaniment and feedforward periods. Note the higher variability for the young group. The variabilities are not statistically different, however it is possible that this finding is due to small sample size.

Figure 13.

The inter-subject coefficients of variations are shown for both groups of children for the anticipatory, accompaniment and feedforward periods. In the anticipatory period the coefficients of variation are virtually the same. However in the accompaniment period as well the entire feedforward period the 10- and 11-year old children show more variability.

Figure 14.

Vertical ground reaction force traces of fifteen trials for three subjects in a) the young group and b) the old group are plotted. The mean of the force traces (\pm SD) for each child appears as the last trial. The period depicted is one second in length. The first vertical line represents the beginning of the anticipatory period. The second vertical line represents movement onset as determined from the accelerometer trace. The third vertical line indicates the end of the accompaniment period. The force traces recorded for the 10- and 11-year old children appear to be less variable intra-subject as reflected in the coefficient of variation data. This suggests that the 10- and 11-year old children were more consistent in their postural adjustments than the younger children. It appears that the 4- and 5-year old children were attempting to remain still while the 10- and 11-year old children each demonstrated a pattern also reflected in their greater inter-subject CoV.

Figure 15.

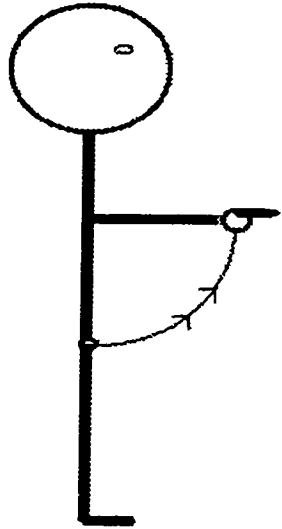
Two postural strategies (feedforward and feedback) for regulating upright stance during voluntary movements are displayed along a continuum of time. Feedforward has been broken down into two components anticipatory and accompaniment. Anticipatory postural adjustments occur before movement initiation, postural

accompaniments arrive within 70 ms of movement initiation and feedback postural adjustments begin more than 70 ms after movement initiation. This representation also indicates that safety and efficiency are at opposite ends of a spectrum, used here as the vertical axis. From Frank and Earl, 1990.

Figure 1

Schematic of Testing Procedure

A



B

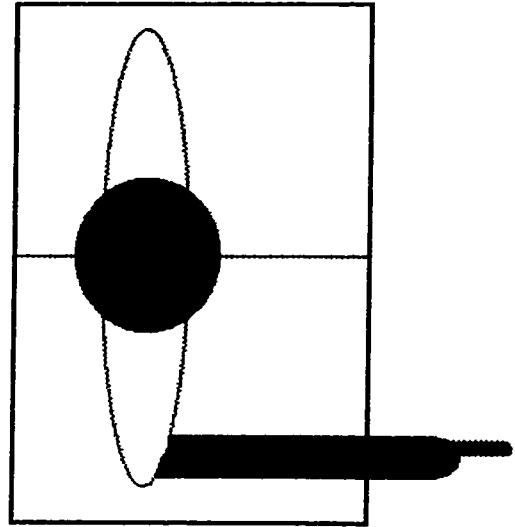


Figure 2.

Sample of Fullwave Rectified EMG Data

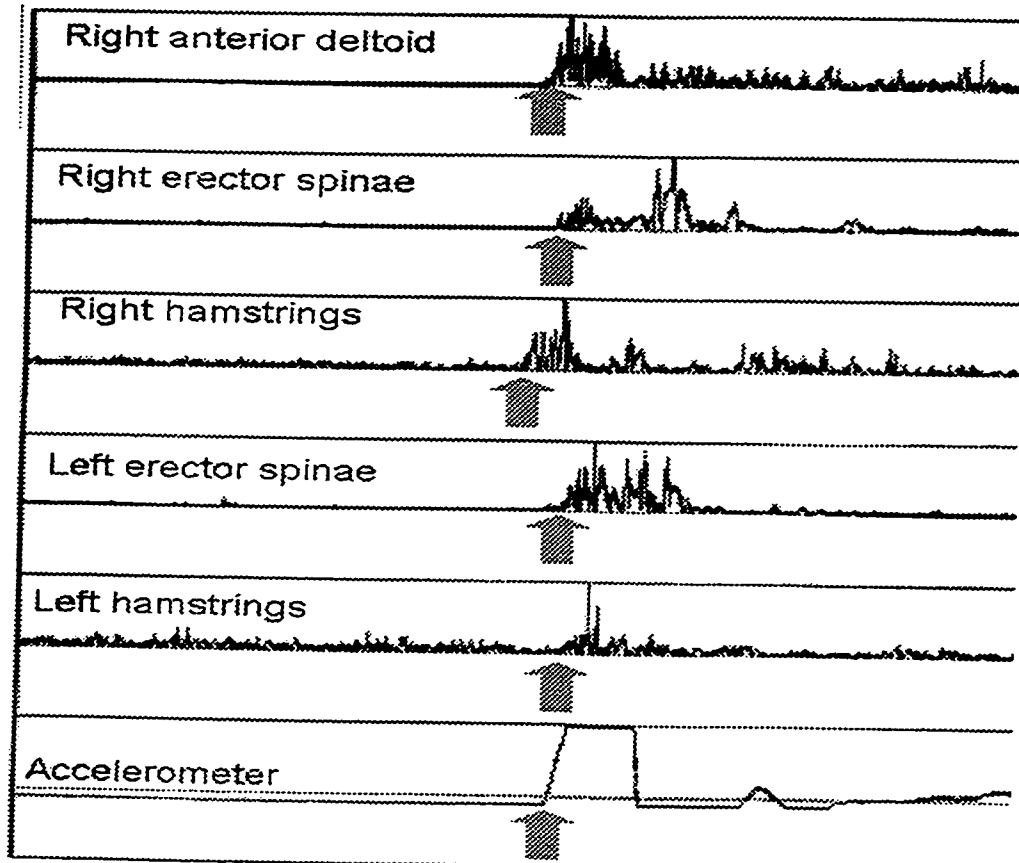


Figure 3.

Vertical Ground Reaction Force Traces - Seven Trials

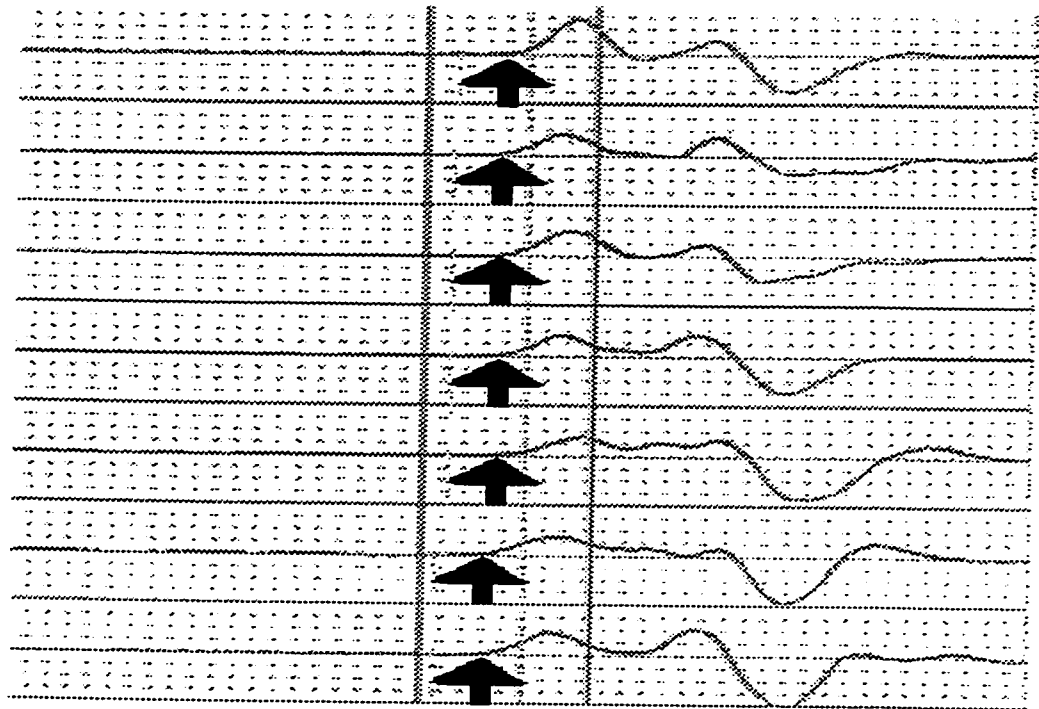


Figure 4

Contrast in CoV

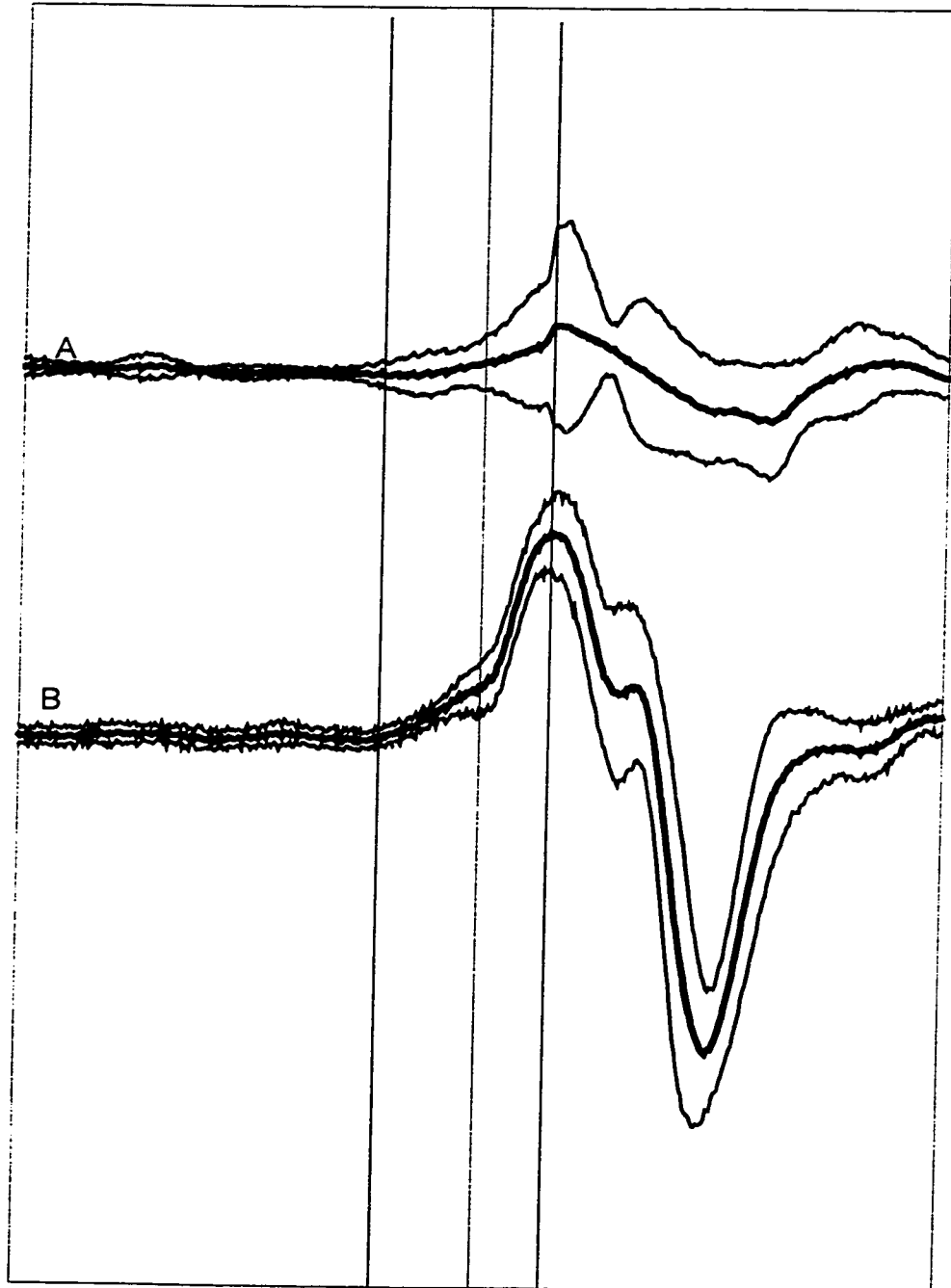
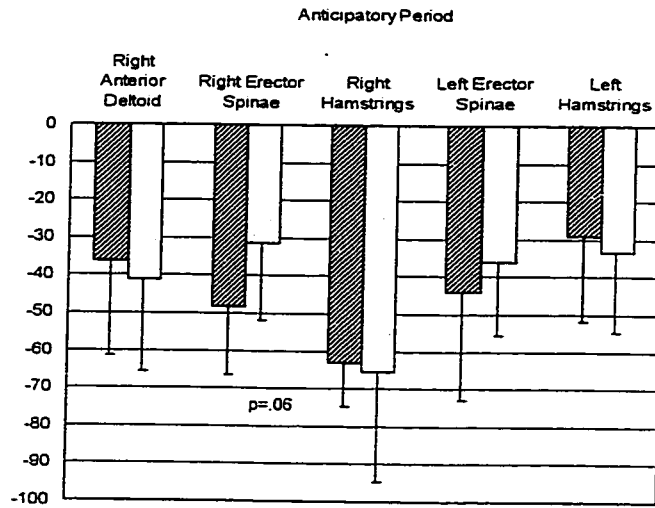


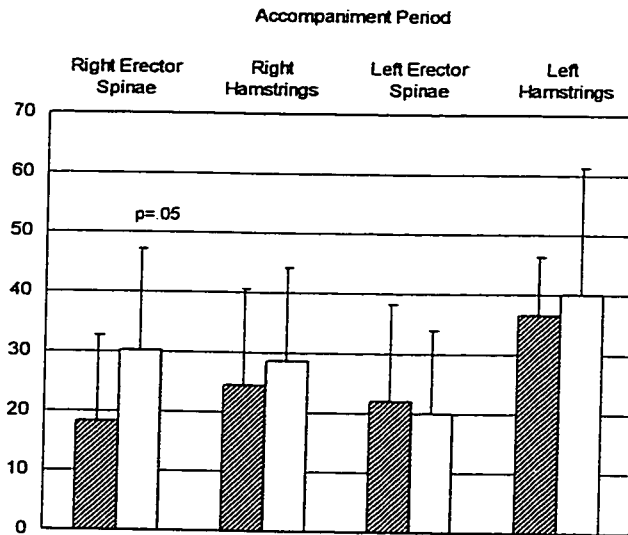
Figure 5

Feedforward Postural Adjustments:
Muscle Onset Latencies Relative to Movement Onset

A



B



C

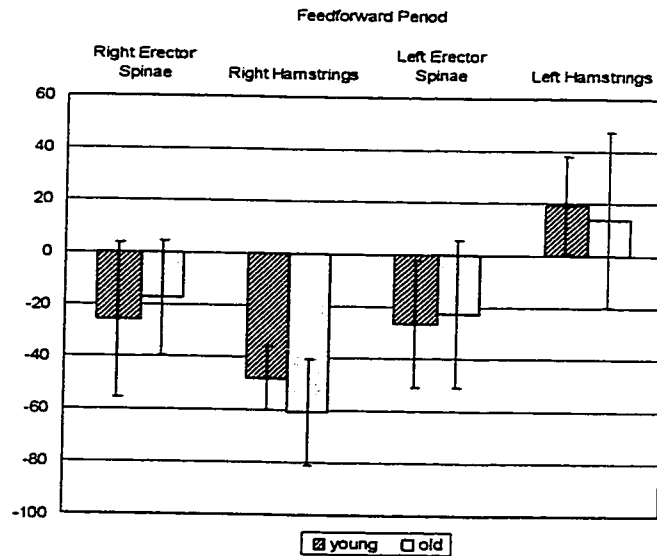
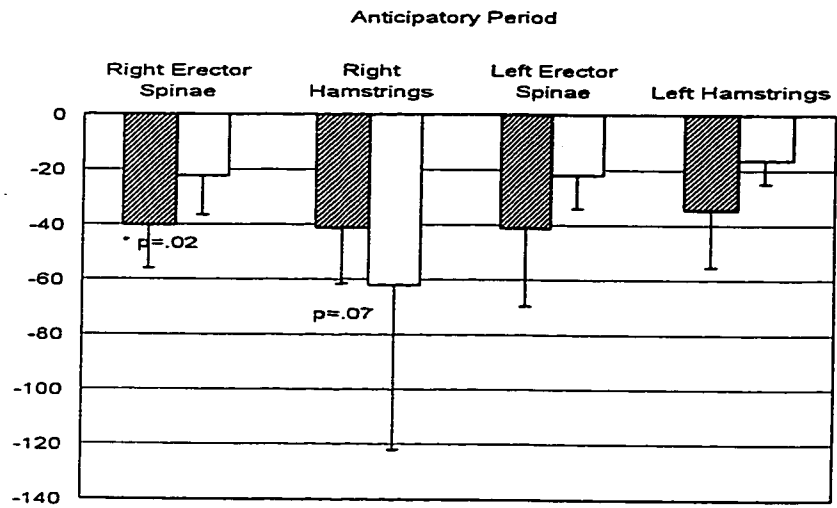


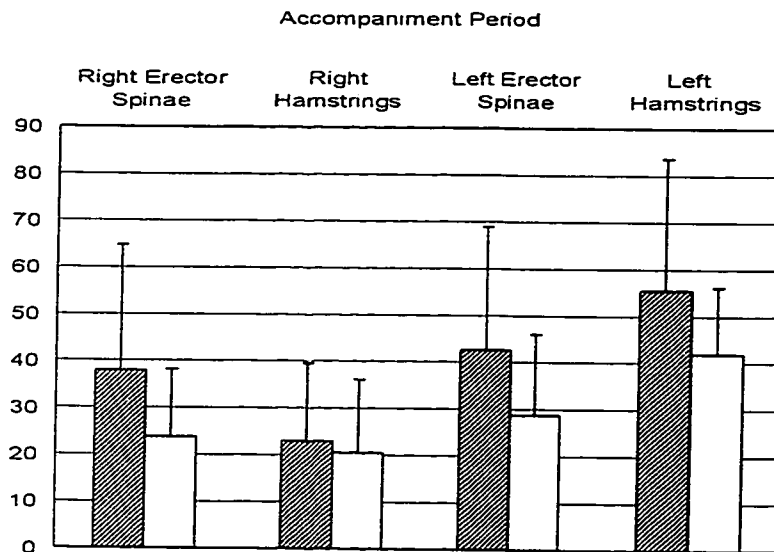
Figure 6

Feedforward Postural Adjustments:
Postural Muscle Onset Latencies Relative to Onset of Activity in the Focal Muscle

A



B



C

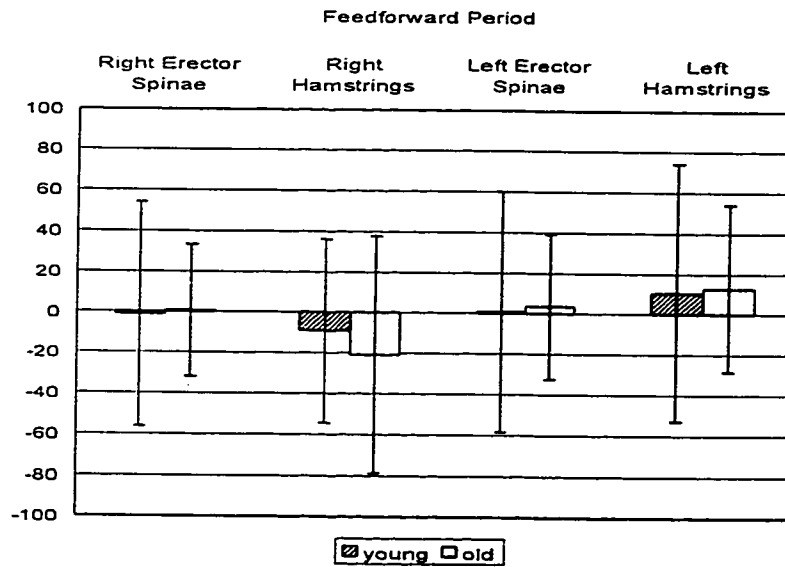


Figure 7

Sequence of Postural Muscle Activation Relative to Focal Muscle Onset

A

Young Children

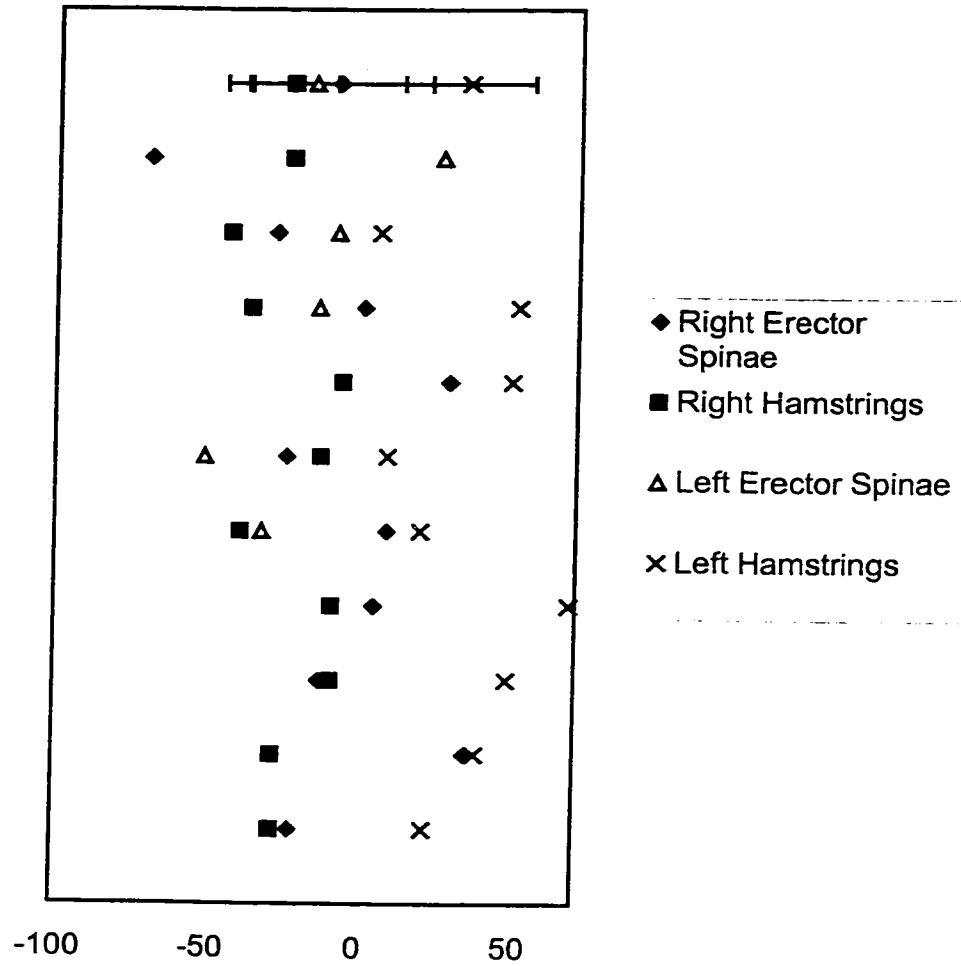


Figure 7

Sequence of Postural Muscle Activation Relative to Focal Muscle Onset

B

Older Children

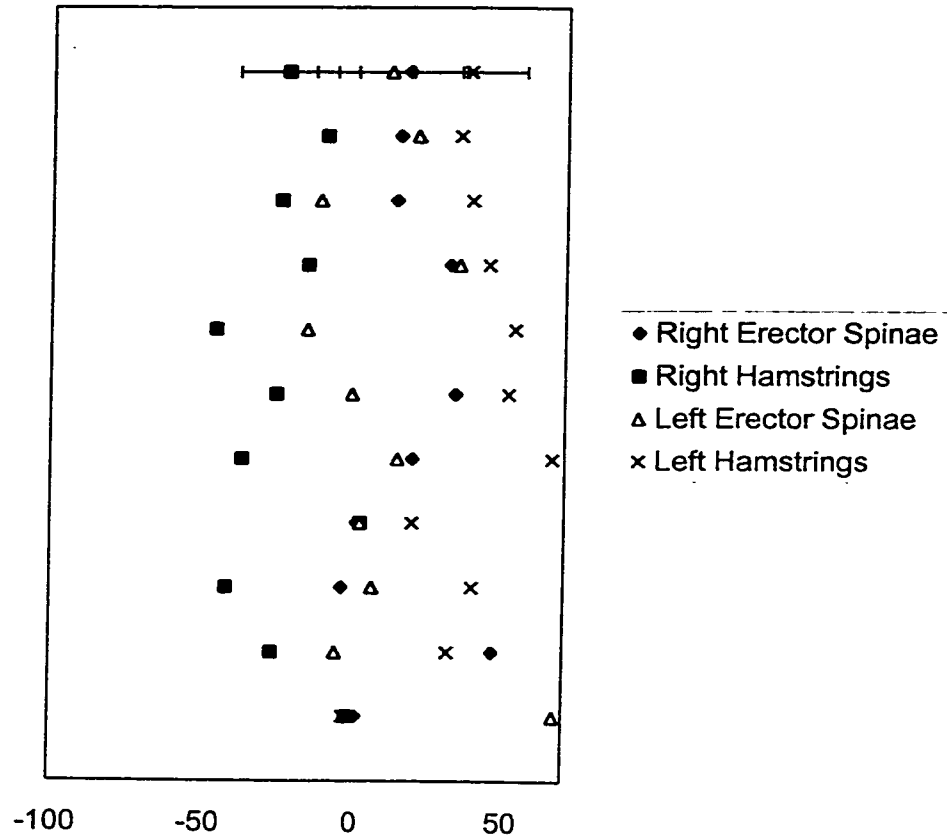


Figure 8
Timing of Feedforward Postural Adjustments Observed in Vertical Ground Reaction Forces
Relative to Movement Onset

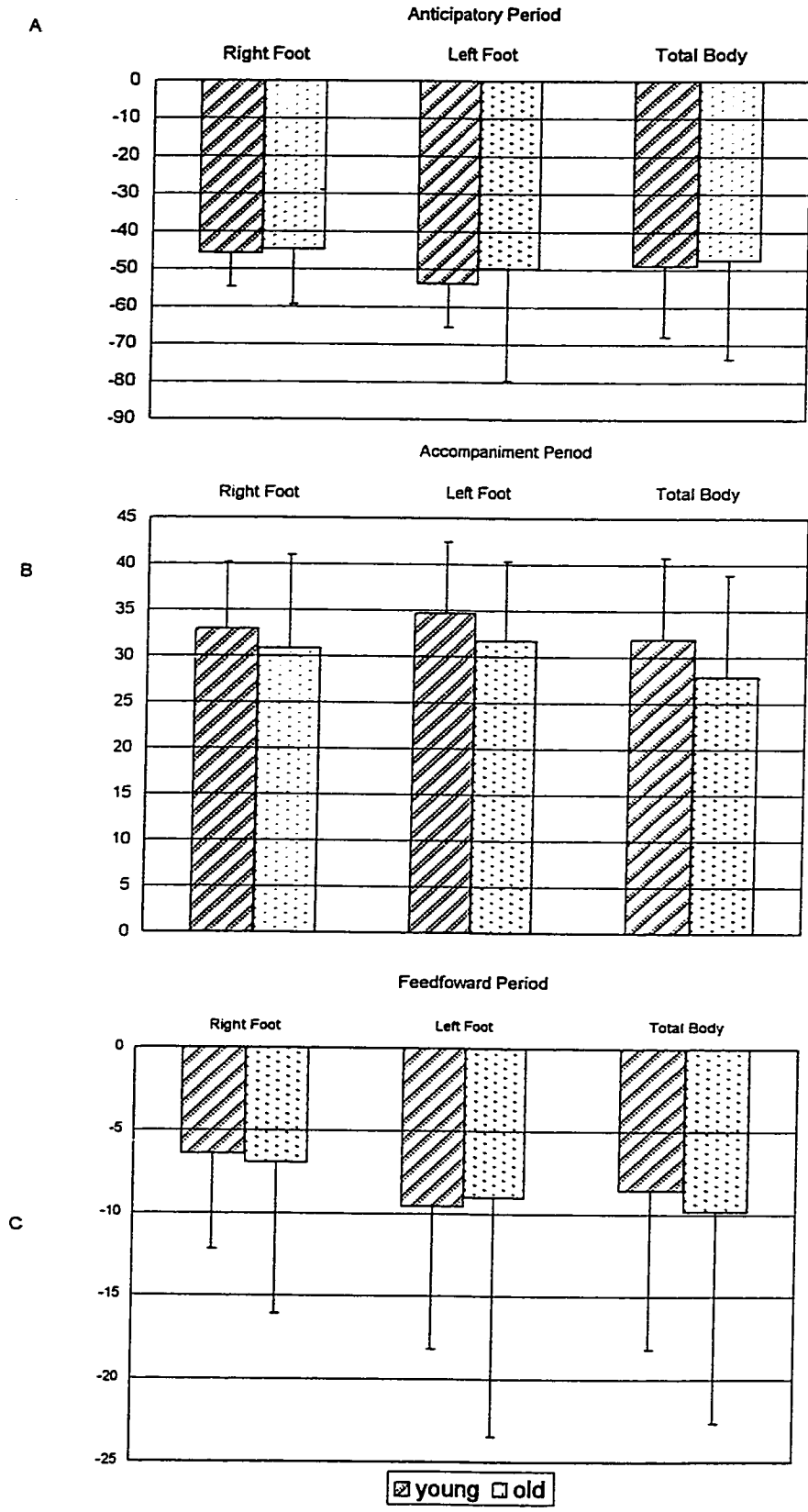
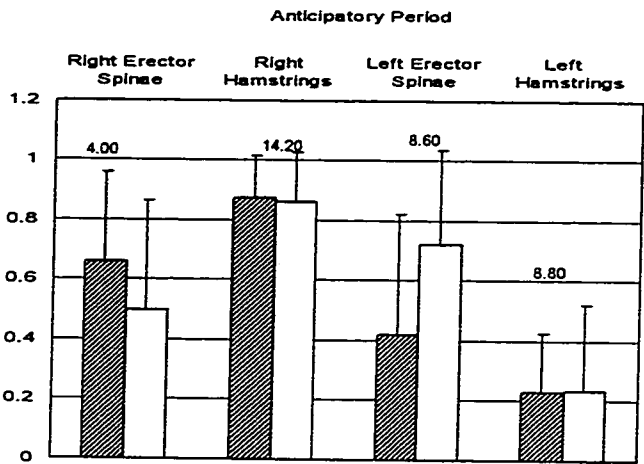


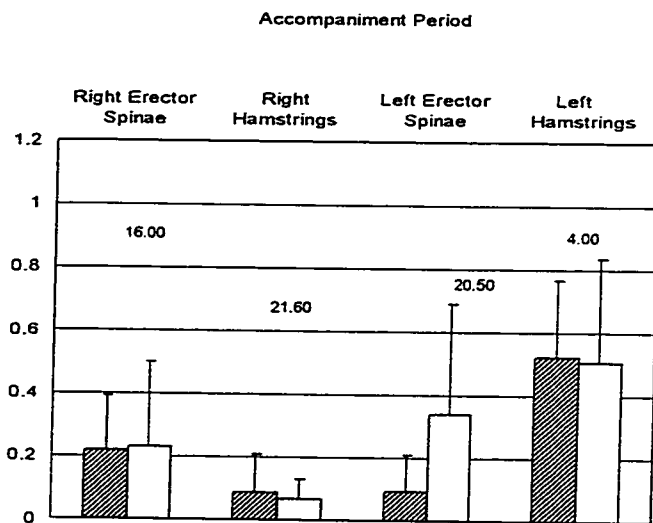
Figure 9

Probability of Recording Feedforward Postural Muscle Activity
Relative to Movement Onset

A



B



C

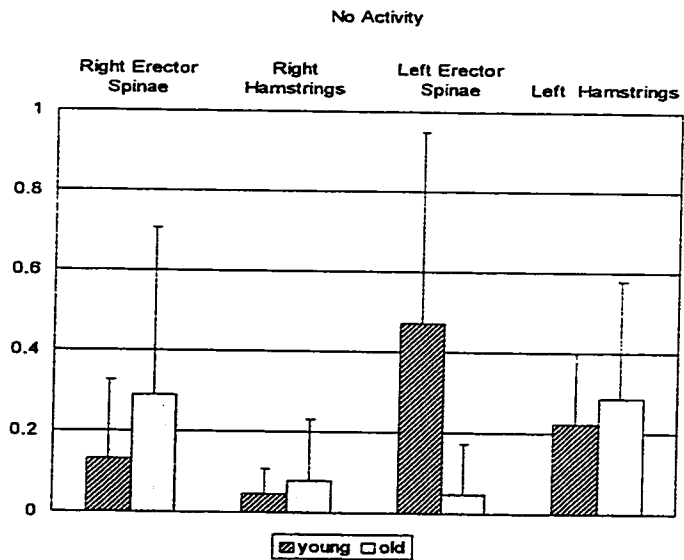
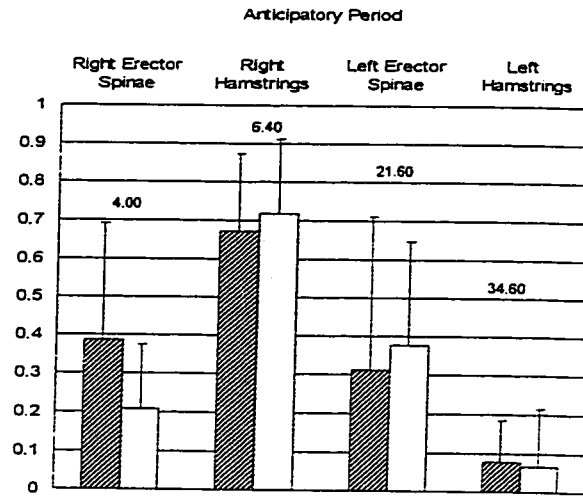


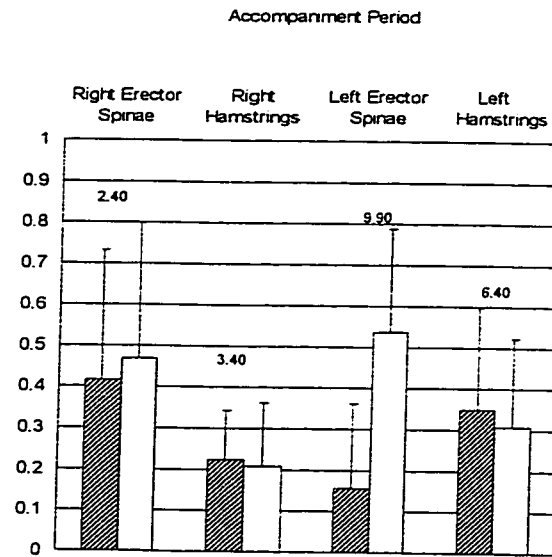
Figure 10

Probability of Recording Feedforward Postural Muscle Activity:
Relative to Focal Muscle Activity

A



B



C

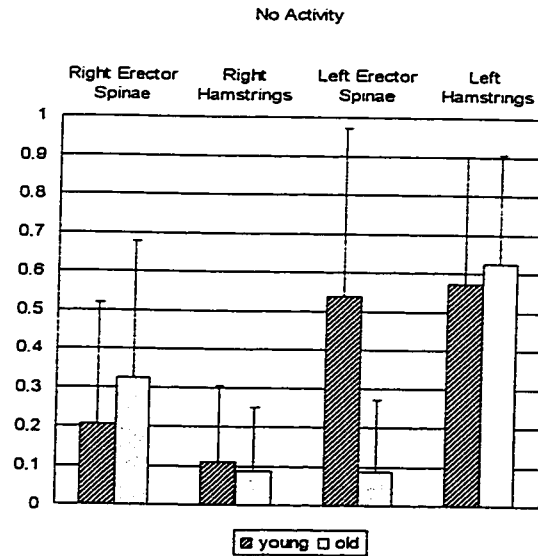


Figure 11

Probability of Change in Vertical Ground Reaction Forces Occurring
In Each Period Relative to Movement Onset

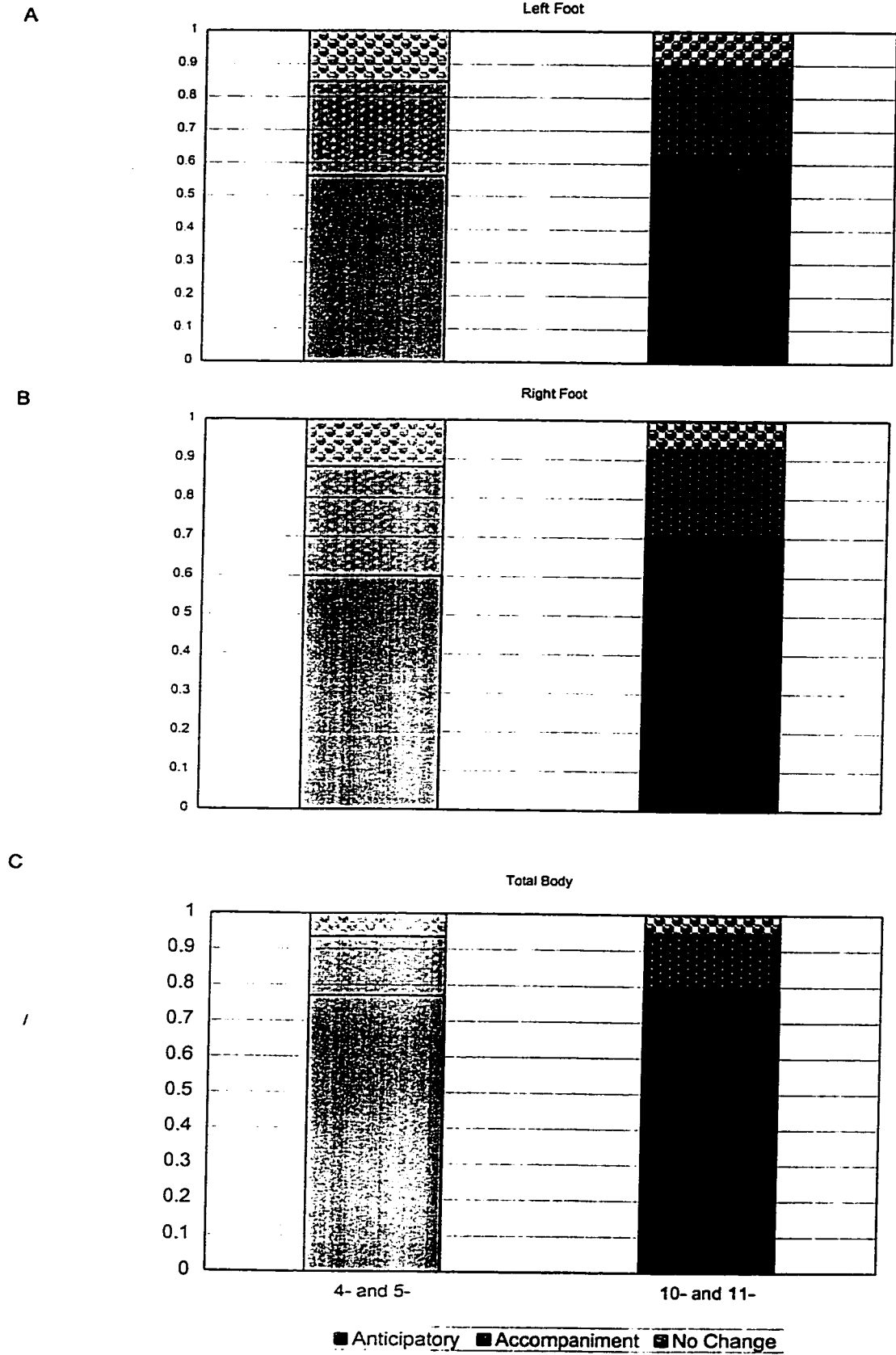


Figure 12

Variability about Vertical Ground Reaction Forces

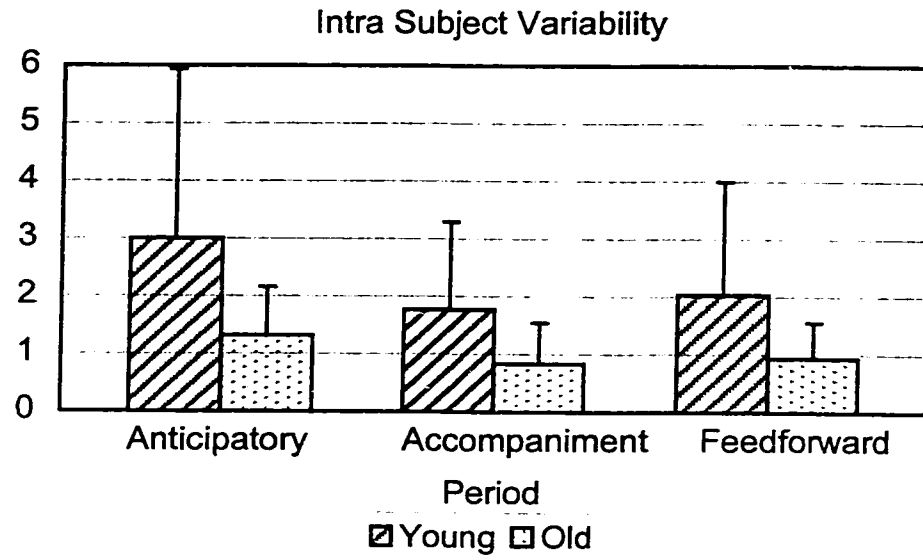


Figure 13

Group Variability about Vertical Ground Reaction Forces

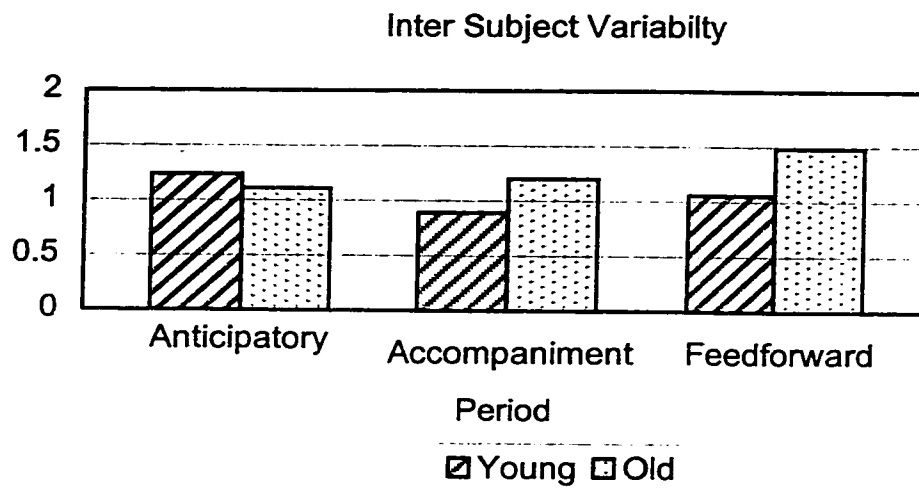


Figure 14

15 Trials of Total Body Vertical Ground Reaction Forces for 3 Children in the Young Group

A

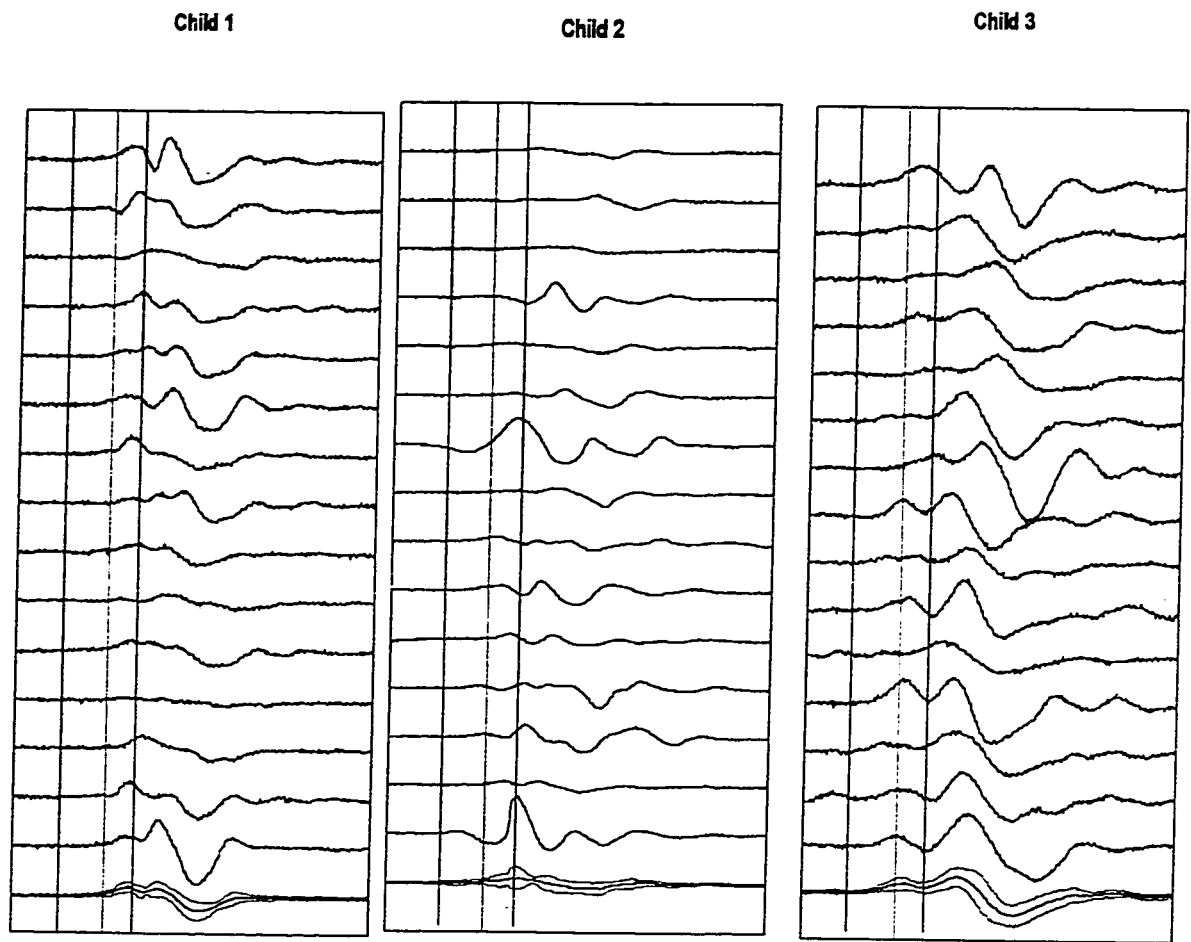


Figure 14

15 Trials of Total Body Vertical Ground Reaction Forces for 3 Children in the Old Group

B

Child 11

Child 12

Child 13

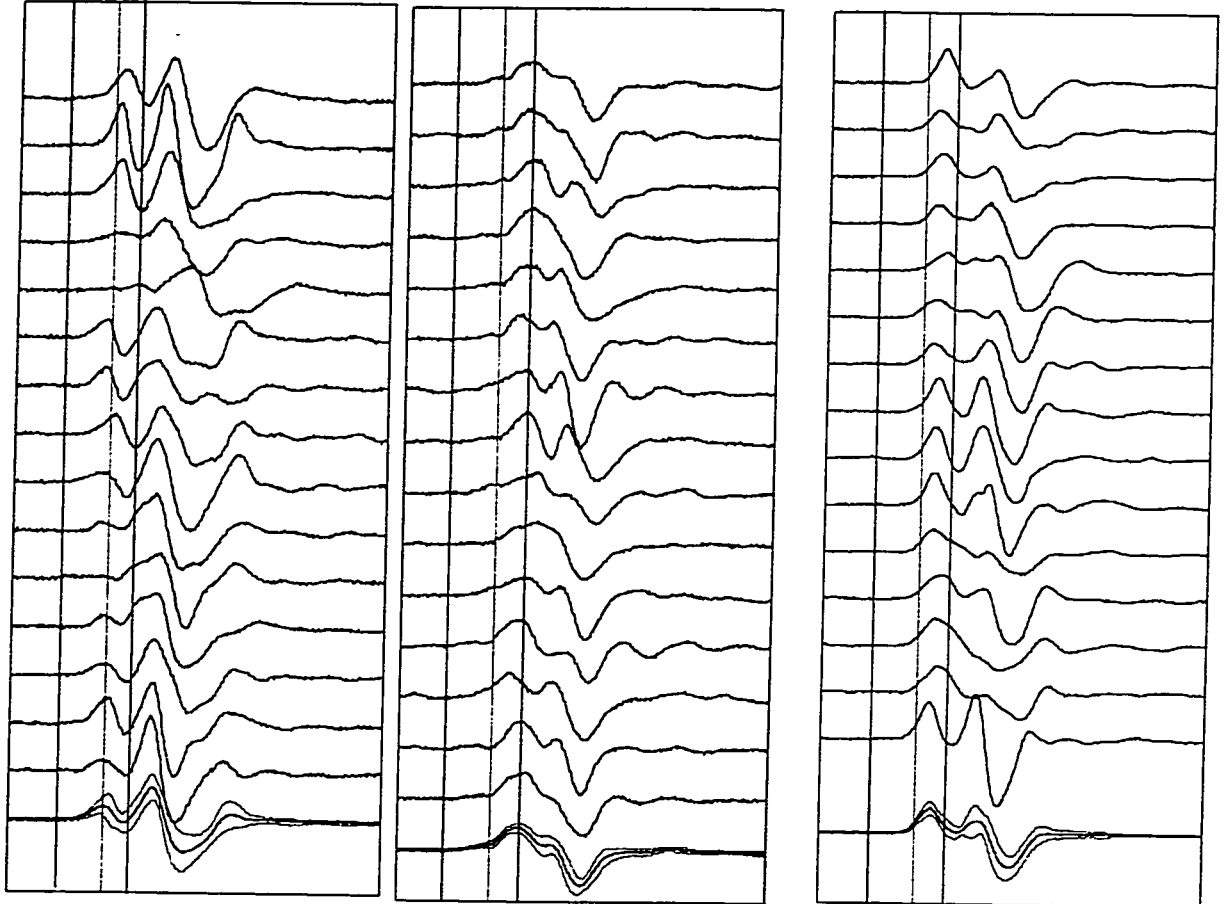
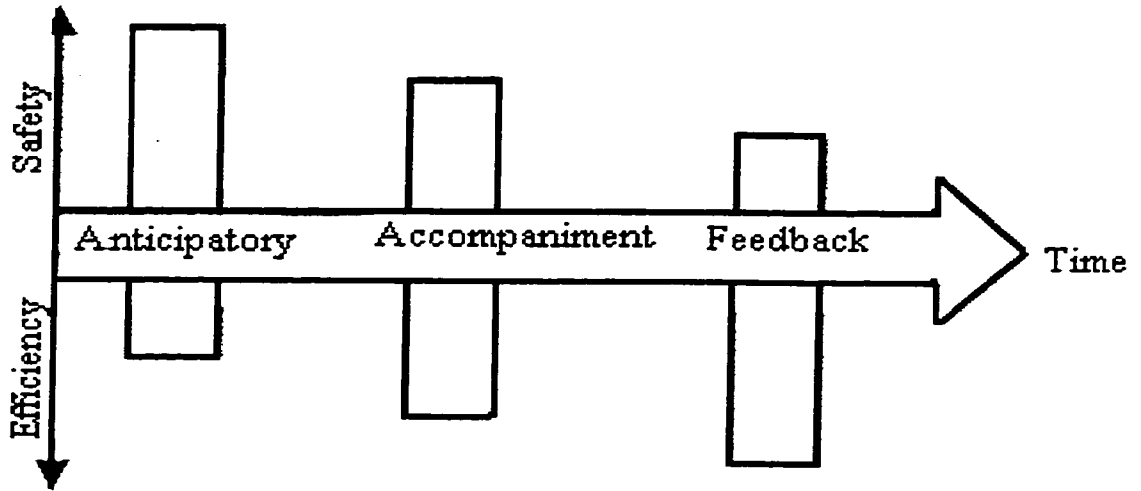


Figure 15.

Theoretical Representation of Posture Control



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Review of Literature

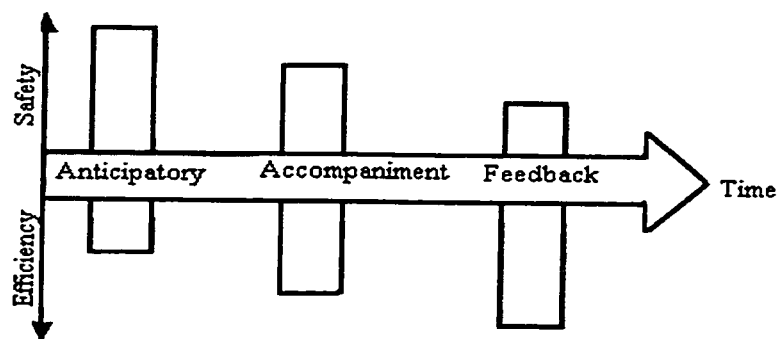
Postural control has two key elements. The first is orientation and the second is equilibrium. Postural orientation consists of locating the body in space with respect to environmental variables such as earth vertical and aligning body parts in a specific orientation with respect to each other (Horak & MacPherson, 1996). Meanwhile, postural equilibrium, more commonly referred to as balance, deals with the many “destabilising influences on the body: external forces due to gravity and to interactions with the surrounding environment, as well as internal forces generated by the body’s own movement” (Horak & MacPherson, 1996). Regardless of the nature of these forces, they all serve to accelerate the body about its centre of mass. People are able to maintain their balance under varying conditions with remarkable ease. However, this motor skill develops as any other, over time. This is an attempt to characterise the pattern of the development.

Postural equilibrium requires the use of two mechanisms, feedforward and feedback. Bernstein (1967) suggested that posture and movement are first co-ordinated by feedback and later by feedforward control (pp 93). Feedback postural control is the reaction based on the afferent visual, vestibular and proprioceptive information that indicates a loss of balance. One component of the reaction, the automatic postural response, consists of postural muscle activation in the legs and trunk, occurring 70-100 ms after a postural disturbance in standing adults (Cordo & Nashner, 1982) and children (Sveistrup & Woollacott, 1996).

The feedforward postural control mechanism has been defined as “anticipating the effect of a movement on posture and co-ordinating the activation of

postural adjustments and the intended (focal) movement to minimise the postural disturbance” (Frank & Earl, 1990). Feedforward postural adjustments consist of two types of adjustments. These postural adjustments may occur prior to the movement and be considered anticipatory. Alternatively, the postural adjustments may occur at the same time as the focal movement and are considered accompaniments. The combination of these two types (anticipatory and accompaniments) are feedforward postural adjustments.

The sequence of the three postural adjustments: anticipatory, accompaniment and feedback, for regulating upright stance during voluntary movement can be demonstrated more clearly with a graphical representation. The postural adjustments are displayed below (figure 1), with anticipatory postural preparations occurring before movement initiation and accompaniments occurring within 70 milliseconds of movement initiation. The feedback mechanism begins 70 to 100 milliseconds or more after movement initiation. This model proposes that the safety and efficiency are diametrically opposed. The earlier the timing of a postural adjustment the safer,



less efficient it is.

Figure 1. *Three postural strategies for regulating upright stance during voluntary movement. Postural strategies are displayed along a continuum of time with anticipatory postural adjustments arriving*

before movement initiation, postural accompaniments arriving within 70 ms of movement initiation, and feedback reactions arriving 70 to 100 milliseconds or more after movement initiation. From Frank & Earl, 1990.

Therefore, the safest but least efficient of the three types of adjustments is the anticipatory adjustment. Accompaniment adjustments are more efficient and finally feedback adjustments are the most efficient but least safe of all postural adjustments.

Feedback Postural Control

Feedback postural control or the automatic postural response deals with the recovery of equilibrium after a loss of balance. For example, if the horizontal surface a person is standing on is translated forward, this causes the centre of mass to pass out of the base of support in the backward direction. A feedback postural response used to regain balance in this situation would be a step backwards. The perception of a loss of balance is based on afferent somatosensory, vestibular and visual input. The timing of the subsequent postural muscle response is quite rapid. These responses may be initiated before there is any significant displacement of the body's centre of mass (Horak & MacPherson, 1996). The specific muscles incorporated into the automatic postural response are modified as a function of the direction and speed of the perturbation, initial body position, the nature of the ongoing task and the state of preparation of the subject.

During unsupported stance, there are three feedback strategies used to regain postural equilibrium. The first is stepping, second is the ankle strategy and third is the hip strategy (Shumway-Cook & Woollacott, 1995, p127-130). The stepping

strategy consists of one possibly, two steps or hops being taken to broaden the base of support to the point where the centre of mass falls well within. The stepping strategy is commonly used in situations where there is either a very rapid or a very large perturbation or where the goal is to maintain a vertical trunk orientation. It is also recorded following smaller perturbations that have not been previously experienced by the subject. The ankle strategy is most commonly used during quiet stance when a subject is on an even firm surface and is exposed to slow, small perturbations. The ankle strategy maintains postural alignment while restoring the centre of mass within the base of support. For example, if the body were to sway forward in response to a backward translation of the surface the subjects are standing on, subjects would produce a plantar flexor torque about the ankle joint. This response would serve to move the centre of pressure forward beyond the centre of mass, thereby reversing the direction of the displacement of the centre of mass and driving it back towards the initial position. This results in reducing the sway. There is little movement at the knee or hip with the ankle strategy since sequential activation of ankle, knee and hip muscles (in a distal to proximal order) serve to maintain the joints in extension as the body rotates about the ankle joint. Finally, the hip strategy is commonly observed following large, rapid perturbations or in conditions where the support surface does not permit the use of the ankle strategy, for example on a very narrow base of support or a very soft surface that will not permit sufficient torque about the ankle. The hip strategy calls for the hips to visibly move forward and the trunk backwards or vice versa depending on the correction needed. The hip strategy and the ankle strategy are quite frequently combined.

In summary there are three feedback strategies used to correct for unexpected postural disturbances: 1) ankle 2) hip and 3) stepping. All three are frequently combined. The goal of feedback postural responses is to regain equilibrium following a loss of balance. Thus, feedback responses are reaction-based mechanisms and are elicited based on afferent somatosensory, visual and vestibular information. Feedback postural reactions in standing begin 70 to 100 ms after perturbation. The most common strategy used in standing is the ankle strategy. Postural muscles are activated in a distal-proximal order.

Development of Feedback Postural Control

The majority of research focussing on feedback postural control uses an anterior/posterior platform translation as the source of the postural disturbance. A longitudinal study of the development of the automatic postural response showed that as early as the stage of development where infants can pull themselves to a standing position, activation of three postural muscles occurred depending on the direction of the postural disturbance (Sveistrup & Woollacott, 1996). Either ventral (tibialis anterior, quadriceps and abdominals) or dorsal postural muscles (gastrocnemius, hamstrings and trunk extensors) were recruited, but this recruitment was inconsistent. By the time the infants were capable of independent stance, the recruitment of three postural muscles was consistent. The recruitment of three postural muscles is considered significant because initially the infants activated one sometimes two muscles together rather than activation of three as we see in adults. The functional significance of the three muscles in adults is the basis of the theory that postural

muscles may function in synergies. A synergy is a functional coupling of groups of muscles that act together as a unit thereby simplifying the control needed from the central nervous system. The authors also reported a decrease in the onset latency of the distal muscles in a significant number of infants with development. This study demonstrated that the feedback postural response elicited during stance begins with activity in a single muscle or paired muscles followed by activation of the postural muscles in functional synergies. These authors suggest that these data illustrate the progressive development of an effective sensory-motor organisation.

Shumway-Cook and Woollacott (1985) stated that directionally specific response synergies are present in children under the age of six. However, they also argued that consistency in the order or recruitment and timings of the synergies is not fully developed at six years of age. These authors used a paradigm where the support surface could rotate, causing plantar or dorsi-flexion. The perturbations were performed under various proprioceptive and visual conditions designed to create sensory conflict. For example, the platform could be rotated to cause dorsi-flexion while the visual information could be manipulated to indicate body sway corresponding to plantar flexion. These researchers proposed that children 4- to 6-years of age are in a transition period, since the ability to resolve sensory conflict in balance control was 1) not present in the 15- to 31- month olds, 2) emerged in the 4-to 6- year old and 3) reached adult form in the 7-to 10- year old group (Shumway-Cook & Woollacott, 1985). Forssberg and Nashner (1982) reported similar findings. Children under the age of 7.5 years could not suppress systematically the influence of inputs derived from the support surface or from vision when these provided

inappropriate orientation information. Forssberg and Nashner (1982) emphasised that the feedback postural adjustments and the context-dependent reweighting of proprioceptive, vestibular and visual inputs are organisationally separate processes and that the hierarchically lower level automatic process matures before the higher level adaptive processes.

In summary, feedback postural adjustments are present in children as young as the pull-to-stand stage of development, although the responses are inconsistent. By the time the child is capable of independent stance, the feedback postural adjustments are much more consistent. With development, a trend towards a decrease of postural muscle onset latency is seen in the distal postural muscles. Also with development, an increase in the number of muscles incorporated into the response is seen. This suggests a progressive development of an effective sensory-motor organisation. There is a transition stage during which children are unable to suppress inappropriate orientation information at approximately four to six years of age.

Feedforward Postural Adjustments

The concept of onset latencies of postural muscles in feedforward postural adjustments can be quite confusing. Greater onset latency in the case of anticipatory activation indicates that the muscles were activated earlier in the anticipatory period relative to the focal muscle onset or movement onset depending on the paradigm being used. Greater onset latency in the accompaniment period indicates that the muscles were activated later, relative to either the focal muscle onset or the movement onset again depending on the paradigm being used. The clearest

representation is a time line, with the zero point in the middle rather than at an end. All numbers prior to zero are negative time counting down to the onset of either the focal muscle or actual movement onset depending on the paradigm being used.

Bouisset and Zattara (1987) suggested that since feedforward postural adjustments depend on the same parameters as the voluntary movement they accompany, they should be considered as pre-programmed. The postural and focal components of the voluntary movement depend on the initial body position, desired focal movement and attention level of the subject. Bouisset and Zattara used a rapid arm flexion about the shoulder executed in the sagittal plane to study feedforward postural. The reaction forces resulting at the shoulder level would provoke a backward and downward acceleration of the body centre of gravity if they were not counterbalanced by postural adjustments (Bouisset & Zattara, 1987). In addition, these forces would create a moment about the body centre of gravity towards the ipsilateral side. However, the destabilising forces were counteracted by feedforward postural adjustments which resulted in an upward and forward acceleration of the body centre of gravity, a lateral acceleration of the body centre of gravity towards the side opposite to the mobile upper limb and a resulting moment about the vertical axis towards the contralateral side before the onset of the focal movement (Bouisset & Zattara, 1987).

Woollacott and Manchester (1993) reported that when young adults executed a rapid unilateral arm movement on a visual cue, the most prevalent pattern of muscle activation was the ipsilateral hamstrings, followed by contralateral erector spinae at a mean latency of 9.4 ms prior to focal muscle onset. The focal muscle, anterior

deltoid, was then activated, followed by contralateral quadriceps at a mean latency of 43.5 ms relative to onset of the focal muscle and finally followed by the activation of the contralateral hamstrings. Substantial variation was recorded between individual subjects (Woollacott & Manchester, 1993). Lee et al. (1987) reported young adults executing self-paced rapid unilateral arm movements recruited the ipsilateral hamstrings followed by the ipsilateral erector spinae muscles at an interval of 101 ms (\pm 77 ms) both prior to movement onset.

Van der Fits, Klip, Van Eykern and Hadders-Algra (1998) completed a study on feedforward postural adjustments accompanying fast pointing movements in adults who were standing, sitting and lying on their backs. The first observation of this team was that the subjects used two focal movement strategies. The first pointing strategy had the anterior deltoid serving as the prime mover while the second utilised the biceps brachii as the prime mover. This second group executed the pointing movement beginning with slight flexion at the elbow, which was extended during the movement. These researchers found that feedforward postural adjustments were considerably less and later in the group using the biceps brachii as the prime mover and hypothesised that this was due to the reduced moment created about the shoulder. In addition, anticipatory postural adjustments were only present in the group that used the anterior deltoid as the prime mover during stance. This can be explained by using the anterior deltoid as the prime mover causes higher inertial moments and consequently would cause greater displacement of the centre of mass.

These researchers concluded that timing, activation rate and amplitude of the dorsal postural muscle activity was position dependent. The dependency was shown

to exist primarily in the erector spinae and hamstring muscles. It seems reasonable that in lying, the role of these muscles would be greatly reduced in maintaining the projection of the centre of gravity within the base of support. In sitting, the role of these muscles would be only slightly reduced, as an upright position must be maintained but over a larger base of support than in standing.

These researchers also explored the effects of increasing the task-load in two ways. The first was by executing bilateral pointing movements and the second was to increase the load on the unilateral movements by adding weight at the wrist. The effect of increasing the load with bilateral pointing was an earlier onset of the lumbar and thoracic extensor muscles in all three positions. The effect occurred primarily in the first 100 ms after prime mover muscle onset. Increasing the load in a unilateral pointing movement did not affect the temporal characteristics of muscle recruitment. This research team concluded feedforward postural control mechanism adapts to changes in the task (Van der Fits, Klip, Van Eykern & Hadders-Algra 1998).

Lee, Buchannan and Rogers (1987) studied the muscle activity subjects generated when asked to execute unilateral voluntary arm movements at various speeds. They reported that at slower speeds, hamstring muscle onset latencies were highly variable and usually lagged movement. However, for faster movements, hamstring muscle onset latencies were correlated with arm acceleration and were recruited before movement. They concluded that behavioural and mechanical conditions affect the recruitment of postural muscles. In this study, the subjects were required to execute an arm movement at the same speed as a visual stimulus and then repeat this same velocity for a self-paced arm movement throughout a range of

different velocities. The hamstring muscles were recruited prior to the anterior deltoid muscles for self-paced movement, but in the case of the visually guided reach, the hamstrings and the anterior deltoid were recruited simultaneously.

Lee et al. (1987) contradict Bouisset and Zattara (1987) by suggesting that postural and focal components of the movement are probably organised by separate yet parallel processes. Lee et al. (1987) argue that firstly, postural muscles were not recruited before focal movement for the fast visually guided arm movements. Secondly, the recruitment order of hamstring and anterior deltoid muscles varied with the behavioural conditions of the trial and was largely independent of arm acceleration. They reported that mean rectified EMG amplitudes of the erector spinae and hamstring muscles were typically positively correlated with arm acceleration but that the correlations were lower than for those between anterior deltoid and arm acceleration.

It should be noted that initial hamstring muscle amplitudes of activation (first 100 ms interval), the anticipatory period, were unrelated to arm acceleration for almost half the subjects (Lee et al., 1987). This was explained by the fact that these subjects demonstrated a hip strategy, first described by Horak and Nashner in 1985. The hip strategy used as a feedforward postural adjustment, calls for the hips to visibly move backward and the trunk forwards. The kinematics are similar to those recorded when the hip strategy is used as a feedback postural adjustment. This pattern differs from the more common motion recorded during rapid unilateral arm movements, where the hips and the trunk both move backwards. It is possible that this less typical strategy reduced the subjects need to increase the magnitude of the

hamstring muscle contraction proportionally with the acceleration. It should be noted that the negative correlation between erector spinae latencies and acceleration only held for slower movements. This difference appears to suggest that the hamstrings and the erector spinae muscles may play different roles in controlling balance and/or posture during arm flexion.

Aruin and Latash (1995) investigated the anticipatory changes in activity of the commonly studied postural muscles of the legs (hamstrings and quadriceps, gastrocnemius and tibialis anterior) and trunk (erector spinae and rectus abdominus) during bilateral, fast, voluntary movements in different directions using EMG and displacement of the centre of pressure. These movements created postural perturbations in the sagittal plane, smoothly ranging in magnitude and direction, forward or backwards. For arm movement in the forward direction, there was a clear anticipatory component scaled with the direction of the movement, in displacement of the centre of pressure in anterior-posterior plane. Maximal backward displacement of the centre of pressure occurred during shoulder movements at 90°, in the sagittal plane, starting position at the body's side and finishing parallel to the floor at shoulder height. They also reported that the strongest and most reproducible dependence of feedforward postural adjustments on movement direction could be seen in the muscles of the trunk rather than the legs. They suggest that the feedforward postural mechanism is concerned with preserving the centre of gravity within the area of support rather than counteracting the reactive forces (Aruin & Latash, 1995).

Aruin and Latash (1995) suggest that the trunk muscles produce a general pattern of postural adjustments, while distal leg muscles (gastrocnemius or tibialis anterior) take care of fine adjustments that are more likely to vary across subjects. The anticipatory postural adjustments by definition should estimate possible balance perturbations due to the planned voluntary movement as well as induce movement that would oppose the movement created by the voluntary movement (Bouisset & Zattara, 1987; Freidli et al., 1988). The efficacy of the feedforward mechanism is frequently sub-optimal; that is to say the perturbations still occur and require a subsequent corrective feedback response (Nashner, 1976; Horak and Nashner, 1985; Deiner et al., 1984; Nashner et al., 1989). Thus, the order of events would be 1) a voluntary movement is planned, 2) the appropriate feedforward postural adjustments occur as does the focal movement, 3) afferent sensory feedback is received, indicating the body requires greater stabilisation and 4) the appropriate feedback response occurs. These researchers (Aruin & Latash, 1995) observed patterns of anticipatory changes in the muscle activation compatible with earlier reports (Cordo & Nashner, 1982; Freidli et al., 1984; Bouisset & Zattara, 1987).

Aruin and Latash (1995) were unable to detect anticipatory changes in the joint angles about the hip, knee or ankle. However the anterior-posterior displacement of the centre of pressure clearly demonstrated an anticipatory component. It should be noted that no comparable forward displacement of the centre of pressure occurred during the arm movements in the backward direction. This may be due to the fact that backward shoulder movements used in this study are

rather uncommon. The subjects practised the movement to sufficiently for it not to be considered an inexperienced movement.

With this type of movement there are two sources of postural perturbation. The first is related to the reactive forces induced by the movement. The second is related to the displacement of the projection of the centre of gravity. In this study, the two acted in opposite directions. The reactive forces pushed the trunk backwards, this was corrected by an anticipatory burst in the tibialis anterior muscle. The resulting forward displacement of the centre of gravity is compensated for by activation of biceps femoris and erector spinae. Although these patterns were seen in the other muscles during movements in all directions, it should be noted that the strongest most reproducible dependence of the anticipatory adjustments on movement direction was seen in the proximal muscles. This would tend to suggest the activation of the proximal muscles counteracted the expected displacement of the centre of gravity rather than the reactive forces.

In summary, it has been well established that muscle activity in the hamstrings and erector spinae muscles before and during a rapid arm movement is intended to maintain equilibrium against self-generated disturbances resulting from the voluntary movement. The onset latency and amplitude of activation of these muscles is dependent upon the initial position of the body and the intended focal movement. In other words, behavioural and mechanical conditions influence the feedforward postural adjustment.

Control of Feedforward Postural Adjustments

The concept that postural leg and trunk muscles are organised as synergies (Horak & Nashner, 1985; Nashner & McCollum, 1985) implies that the relationships between EMG parameters for synergistic muscles should be stable with changes in the control variables, such as initial body position, the focal movement, speed etc, which influence the degree to which a synergy is activated (Lee, 1984). For example, in a self-paced unilateral rapid arm movement from an auditory cue, the effect of increasing the load should not affect the temporal aspects of the EMG pattern, although it is likely that the absolute EMG amplitudes would be affected. Van der Fits et al. (1998) demonstrated that the temporal characteristics were not changed. However, Lee et al. (1987) found only minimal evidence that anticipatory EMG amplitude in hamstrings and erector spinae muscles was consistently correlated for the arm accelerations which subjects produced during shoulder flexion. The recruitment order of the two muscles was more consistent. Lee et al. (1987) found a great deal of variability in the ratio of leg and trunk muscle EMG amplitude, in contrast to reports of constant ratios for feedback postural adjustments (Nashner, 1977; Nashner & Cordo, 1981). Although the recruitment order of hamstrings and erector spinae muscles was consistent, the muscle onset latencies were uncorrelated with amplitude, for almost half the subjects. Consequently, the relationship between quantitative EMG characteristics of hamstrings and erector spinae failed to demonstrate temporal or amplitude scaling. Only the recruitment order remained constant over the range of arm accelerations tested.

Two results of this study (Lee et al., 1987) suggest that postural and focal muscles are organised in parallel as opposed to a single central command as suggested by Cordo and Nashner (1982) and Bouisset and Zattara (1987). First, postural muscles were not recruited before focal muscles for the fast, visually guided arm movements. Second, the recruitment order of hamstrings and anterior deltoid muscles varied with the behavioural conditions of the task and was largely independent of arm acceleration. Lee et al. (1987) had expected that the interval between the hamstring and the anterior deltoid muscle onset would increase with arm acceleration. Their findings that arm acceleration did not influence the interval the hamstrings and the anterior deltoid onset led them to the conclusion that postural muscle and focal muscles are organised separately but in parallel.

Brown and Frank (1987) examined the influence of event anticipation on feedforward postural adjustments associated with voluntary movement, by asking the question: "are the two components (posture and task) activated as part of one command for movement or are the feedforward postural adjustments controlled through a separate process of motor preparation"? They hypothesised that if feedforward postural adjustments associated with a voluntary movement were influenced by the preparatory set (if subject know what direction they will have to move in), the timing between activation of postural adjustments and the intended movement would not be fixed. The subjects stood holding a handle similar to the handlebars of a bicycle. Based on the visual cue they received they were to push or pull on the handle. The procedure was designed such that there were three levels of preparatory "set": 20%, 50% or 80% certainty of the desired direction of a handle

pull/push. The researchers expected that subjects would respond faster and that the activation of postural muscles would occur earlier relative to the triggering of the primary or focal muscle activation when the preparatory set was high. The results showed that three of the six subjects demonstrated an effect of preparatory set on their reaction time performance. It was unclear as to why the other three subjects did not. It was proposed that they were cautious and ignored the probability information. The occurrence of error, a push in place of a pull for example, was quite low, only seven errors among 180 trials. Subsequently frequency of errors was ruled out as a possible explanation.

Of the three subjects who were influenced by the probability information, it was clearly demonstrated that preparatory set influenced the temporal co-ordination between postural muscle and focal muscle activation. However, this effect only occurred when reprogramming the response was required. When the subjects responded in the opposite direction to that forewarned (0.20 probability), postural and focal muscle onset times were differentially influenced. Reprogramming of the response required additional time for activation of the focal muscle but not the postural muscles. Based on the original hypothesis that if postural muscle and focal muscle were controlled by one command the postural-focal muscle onset latency would be fixed. However, the results indicated that the focal muscle activation and that of postural muscle must be controlled by separate controllers. This contradicts Cordo and Nashner (1982) and Bouisset and Zattara (1987), who reasoned if the correlation between onset times of postural and focal muscles was high (indicating a fixed temporal relationship exists) control by a common central command was

implied. Cordo and Nashner (1982) reported low correlations and could not support their hypothesis. It would appear that parallel but separate processes are the correct representation of the control.

The reasoning used by these researchers is perhaps too black and white, it does not allow for any extraneous variables. Even if a high correlation was consistently found, control by a central command should not be assumed. Postural and focal muscles could be activated at a fixed latency because of biomechanical necessities. Consequently, it remains possible that activation of postural and focal muscle could be controlled by separate command signals. Brown and Frank (1987) expected that postural muscles would be activated earlier relative to the triggering of the focal muscle activation when the preparatory set was high, when in fact the postural-focal latency remained fixed for conditions of high and neutral preparatory set. This could reflect the possibility of an optimal threshold.

In summary there has been some disagreement over whether feedforward postural adjustments and the focal movement are organised in parallel or by one central command. Some researchers assumed that if there was a high correlation between onset times of postural and focal muscles that this would suggest they were organised by a single central command. Mixed results were reported, therefore it cannot be assumed that these two factors would be fixed under a central command. As yet, the actual mechanism is unclear. Research has shown that focal muscle onset latency changes with preparatory set but that postural muscle onset latency does not. It has been shown that the recruitment order of the postural muscles remains constant.

Feedforward Postural Control in the Elderly

As with research on development of feedforward postural adjustments, research on age-related changes in feedforward postural adjustments has been limited. Inglin and Woollacott (1988) examined age-related differences in the feedforward postural adjustments associated with arm movements. The task in this study was a push/pull scenario that could be presented as either a simple reaction time or a complex reaction time. In the simple reaction time task, subjects stood holding a handle and were told to push the handle when the command was given, other subjects were told to pull the handle when the command was given. In the complex reaction time task, subjects did not know if they were to pull or push the handle until the command was given. The young adults demonstrated a mean onset latency of the gastrocnemius and tibialis anterior muscles in the 150-200 ms range prior to movement onset. Compared to young adults, the older adults (64 to 76 years) had significantly later onset latencies in the distal postural muscles (push: tibialis anterior and pull: lateral gastrocnemius) when required to complete a simple reaction time arm movement. There was one exception in this finding. During a simple reaction pull task, the onset latency of the gastrocnemius muscle was not significantly different between age groups. This similarity appears to be a bias in the effects of ageing on the flexors and extensors of the ankle for feedforward postural adjustments. These authors reported tibialis anterior showed greater onset latencies with ageing than did gastrocnemius in feedback responses to external perturbations (Inglin & Woollacott, 1988).

A significantly large increase in the onset latency of the focal muscle relative to the command to either push or pull, was also noted for the older subjects. These authors reported that the increase was greater than that due to the increase in the onset latencies of the postural muscles. Two explanations were offered. First, the activation of the focal muscle system may be more greatly affected by age than the postural muscle system slows with age. Consequently, the activation of the focal muscle slows with age, thereby limiting the speed of the focal movement and the required feedforward postural adjustments (Shumway-Cook & Woollacott, 1995). Alternatively, the authors suggest that it is possible that the deterioration of the postural control system limits the speed of the voluntary movement by delaying the onset of the voluntary muscle response.

This study also demonstrated that a greater percentage of the young adults showed the distal to proximal activation pattern in the postural muscles. The authors concluded this more efficient sequence of the postural muscle response activation seems to be disrupted in many of the older adults for this focal movement (Inglin & Woollacott 1988).

Woollacott and Manchester (1993) attempted to determine whether changes in response characteristics identified by Inglin and Woollacott (1988) were due to changes in strategy, by asking if focal movement velocity was the mediating variable between age and lack of feedforward postural adjustments. An arm-raising task initiated via a visual cue rather than auditory cue was used. Various velocities of reaching were used and no statistical differences in arm raising velocities were found between the younger and older subjects. No differences were found in the focal

movements but there were differences in the postural adjustments between age groups. As no differences in velocities of reaching were found all differences were considered to be as a result of ageing. In the older subjects, the contralateral erector spinae muscle was activated later relative to the focal muscle than in the younger subjects. Additionally, the older subjects also demonstrated more frequent activation of the contralateral quadriceps at all velocities of arm movement. Delays in the contralateral erector spinae muscle onsets caused the postural-focal muscle latency to be diminished in the older subjects. These results contrasted those of the earlier study. The authors acknowledge that the differences in the paradigm and subsequent postural support available could be the cause of these conflicting results. The previous study used a push/pull scenario with subjects holding onto a handle. If the subjects were also using the apparatus for support, programming of the postural adjustments may have been simplified and the latencies less affected by age.

These authors hypothesised that the delays in onset of the postural muscles, the ipsilateral hamstrings and erector spinae muscles in the older subjects may be caused by cognitive factors; such as using excessive caution or inaccuracy in the estimation of the disturbance caused by the focal movement. The researchers concluded that these differences are as a result of ageing. However, there was a strong correlation between subjects who displayed the most abnormal response and those showing a high number of subclinical neural deficits in the following areas: proprioception, vestibular, hearing, visual, cerebellar, sequential motor actions, balance and range of motion. The age-related differences identified in this study may actually be due to neural deficits, which may or may not be due entirely to ageing.

In summary, limited studies have reported the effects of ageing on feedforward postural adjustments. The elderly subjects demonstrate increased onset latencies of the distal postural muscles. Elderly subjects demonstrated a large increase in focal muscle onset latency. A greater proportion of young adults demonstrated the distal to proximal activation pattern of the postural muscles than elderly subjects. No significant differences existed between age groups in velocities of focal movements. Sub-clinical neural deficits were linked to abnormal postural responses in the elderly.

Development of Feedforward Postural Control

In an early study of the development of feedforward postural control of upright stance, children were asked to rise from a flat-footed stance to an "on tiptoe" position (Haas, Deiner, Rapp & Dichgans 1989). Children between the ages of four and six years demonstrated feedforward postural adjustments similar to those recorded in school aged children, between 8 and 14 years of age. The feedforward postural adjustments consisted of a forward shift in the centre pressure prior to the lifting of the heels. Children under the age of four were unable to demonstrate the task during the experimental sessions. Thus, the data seemed to suggest that feedforward postural adjustments developed as late as four years of age. However, these researchers commented that infants demonstrated feedforward behaviour while sitting and reaching for an object or while crawling or walking although no data were presented to support this statement. The authors stated that the feedforward behaviour demonstrated by the infants apparently appears shortly after they are able to maintain a sitting, crawling or upright stance position. This contradicts the

hypothesis that infants are unable to take advantage of feedforward behaviours (Kelso, 1982 p. 56). If feedforward postural adjustments are present in children under four years of age, it is possible that the task, rise to tiptoe, is inappropriate for studying the development of these adjustments. One possibility is that children under the age of four have not yet mastered the motor skill of rising to an "on tiptoes" position. Another possibility is that the children have acquired the motor skill but lack the ability to focus their attention in a complex task paradigm.

When a different paradigm was used to study feedforward postural adjustments in children aged 4 to 14 years (Riach & Hayes, 1990), feedforward postural adjustments were identified, even in the youngest children. However the postural adjustments recorded in the youngest were neither consistently present nor when present, consistent. The task used was a unilateral rapid arm motion and feedforward postural adjustments were identified as shifts in the displacement of the centre of pressure (COP) in the anterior-posterior and lateral directions. The feedforward postural adjustments recorded were posterior shifts in the COP prior to the onset of arm acceleration. These adjustments were recorded in five of the nine subjects in the age range of four-six years. In the older children aged 7-10- years, 15 out of 15 demonstrated feedforward postural adjustments in the anterior-posterior plane. Meanwhile in the oldest children, aged 11-14 years these adjustments were recorded in 6 of 8 subjects.

Two test procedures were used; one was a simple reaction time task while the second task involved a more complex choice reaction time task with a variable foreperiod. The results of children who completed the simple reaction time task

were compared to the results of children of the same age who completed the complex task. At all ages, children were less likely to initiate anticipatory postural adjustments in complex reaction task than in the simple reaction time task (Riach & Hayes, 1990). Since complicated tasks resulted in fewer and more variable postural adjustments, studies of the development of feedforward postural adjustments should incorporate a simple task in order to increase the likelihood of eliciting feedforward postural adjustments.

Hay and Redon (1999) compared the postural adjustments associated with self-initiated disturbances to those associated with externally initiated postural disturbances. The children were asked to hold a weight equal to 5% of body mass. The child would either drop the weight (self-initiated postural disturbance) or an experimenter would remove it without notice (externally initiated postural disturbance). The amplitude of self-initiated disturbance decreased between the three-to-five year olds subjects and the six-to-eight year olds, and increased again in the 9- to 10-year-olds and adults. It is possible that once the children have acquired the skill of anticipating the effect of the self-initiated disturbance by 9- to 10-years of age, they become more confident in their ability to remain stable, therefore allowing greater amplitude in the resulting postural disturbance, rather than trying to remain completely still. The reduction of the amplitude of the resulting postural disturbance between the youngest group and the 6- to 8-year olds suggests that the six to eight year old children are indeed attempting to remain completely still. There were no significant differences between the two older groups.

Van der Fits, Otten, Klip, Van Eykern and Hadders-Algra completed a longitudinal study of ten infants between 6 and 18 months of age, reaching from a seated position (1999). These authors reported that at six months of age, the neck extensor, neck flexor and lumbar extensor muscle were activated in an anticipatory fashion in 40% percent of the trials. By 18 months, the frequency of the anticipatory muscle activation in these same muscles had increased to 80%. However, the rectus abdominus, hamstrings and rectus femoris muscles were rarely activated (+/- 10%). This is in contrast to seated adults who activate a combination of neck extensor, lumbar extensor, neck flexors and rectus abdominus (Van der Fits et al., 1998) with a reaching motion similar to that of the infants. In general, the six-month-old infants activated neck extensors, neck flexors and lumbar extensors mostly in isolation or infrequently in combination with at least one of the ventral neck and trunk muscles.

These authors considered anticipatory activity to be present if the postural muscles were activated before the arm muscle that initiated the movement. They determined that the frequency of feedforward postural activity was “significantly related to onset of independent stance and walking, but not to the emergence of other motor skills, nor the type of chair support” (Van der Fits et al., 1999). The ability to adapt postural muscle activity to task specific constraints such as the amount of support, increased load, velocity of the reach and their initial posture/position etc, was present from eight months onward. Asymmetries of postural muscle activation during unilateral reaching were identified in eight-month-old infants. The probability of feedforward postural adjustments on the ipsilateral side was different

from the contralateral side; thus, indicating the feedforward postural adjustments were task specific.

Prior to this study, the earliest evidence of feedforward postural adjustments in children was at four years of age. Anticipatory postural adjustment development was suggested to be related to the emergence of independent stance and walking. This was interpreted by the research team to indicate that development of feedforward control is an important factor in the development of bipedal motor behaviour, an important milestone in the development of posture control (Van der Fits et al., 1999). Independent stance and walking are indeed important motor milestones. Emergence and development of feedforward postural control associated with reaching or any other specific task allows the child to learn that with a new focal task there are new postural manoeuvres to be discovered and mastered. Common sense would dictate that feedforward postural control is an important factor in independent stance and walking. However, to say-so based purely on the findings of this reaching from a seated position study would appear to make too great an assumption.

In summary, the earliest feedforward postural adjustments identified occur in infants between six and eight months of age. Feedforward postural adjustments are defined here as postural muscle activity prior to focal muscle activity in both a neck and trunk muscle. By eight months of age differences in postural muscle activity are seen between the ipsilateral and contralateral sides. Previous research had been unable to record any feedforward postural adjustments in children under the age of four years. Children four to six years of age had been able to demonstrate feedforward postural adjustments quantified by anterior-posterior displacement of the

centre of pressure. However, inconsistency in the presence of these adjustments was reported for the young children.

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Appendix A

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School of Rehabilitation Sciences

LETTER OF INFORMATION AND CONSENT

(Parent or Guardian)

Posture Control in Children

This letter of information and consent, which you are being asked to read and sign, indicated that you agree to allow your child to participate in the study. The letter is designed to outline the research project and to explain what you and your child's involvement in this study will entail.

PURPOSE: This aim of this research is to learn more about the way children learn to maintain their balance while reaching for objects. The procedures used during this testing are experimental, but there are no other tests which will give us this information. There are no direct medical benefits to individual participants which can be derived from the study. This study is being conducted for the fulfilment of the thesis requirement for Jennifer McGregor's Master's degree.

PROCEDURE: At the start of the testing session, we will record your child's age, height, weight, foot length and sex. We will then ask you to assist us in placing 5 disks that will measure the muscle activity over the muscles of the front of the shoulder, lower back, and back of the thigh. We will also be placing a disk on your child's wrist, to measure how fast your child reaches. Your child will be asked to stand with their arms at their sides. When they hear a beep they should reach as fast as they can with their right hand. Once their arm is parallel to the ground they will stop and leave their arm in that position until they hear a second beep indicating that the trial is complete. There are fifteen trials, each lasting four seconds. Your child will be video taped while performing these tasks. In addition to the video information, the information about the muscle activity and the reach speed, the forces that your child produces while reaching will be recorded using a weight scale mounted in the floor. This testing session is expected to last approximately 1 hour.

RISKS AND BENEFITS OF THESE TESTS

Your child may find it uncomfortable when we apply and remove the tape holding the disks on the skin. We will minimise discomfort by using 3M Skin Tape™, which is specifically designed for use of sensitive skin. We also have a glue dissolvent, formulated for use on skin, to remove the tape. The skin will then be washed and a moisturising cream will be applied to the area. Your child may find that he/she gets tired. We will schedule regular rest breaks and will stop the test at any time if you see signs of fatigue or if your child indicated that he/she is tired.

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YOU MAY STOP THE TEST AT ANY TIME

You may stop the test at any time simply by telling the person controlling the test that you do not wish your child to continue. You may also withdraw your child from the experiment, at any time without fear of reprisal, simply by informing the person controlling the test. During all testing sessions you will be present in the room.

You will be reimbursed \$5.00 for your parking fees at the University and an honorarium of \$20.00 will be issued upon completion of the data collection period. You will receive no other direct benefit from this research. The information which results from your child's test will be used to further understand the steps or pattern of human development when learning posture control during voluntary movement, such as reaching.

All records from this research, including the video cassette, will be kept confidential and will not be given or shown to anyone other than the researchers involved in the study unless you give us written permission to do so. No name will be attached to the data and anonymity will be assured by coding procedures. Only researchers involved in the project will view the original data collected (muscle activity, force and video). Your child's results may appear in publication, but he/she will not be identified by name.

CONSENT

In signing this informed consent form, I acknowledge that I have read and understood all of the information in this document. Before signing, I have been allowed to observe the procedures that will be used in the research project. I acknowledge that my child will be videotaped. I have been instructed that I am free to withdraw my consent to participate in the project at any time. I understand that I can contact the project directors, Dr. Heidi Sveistrup (562-5800 ext. 8016) and Jennifer McGregor (562-5800 ext. 8085) with questions about the experimental procedures and that I can contact Dr. Roger Proulx, Chair of the Human Research Ethics Committee (562-5800 ext. 4251) regarding any ethical concerns that I might have.

DATE:

PARENT'S NAME (please print):

PARENT'S SIGNATURE:

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INFORMED CONSENT FOR THE USE OF VIDEOTAPES FOR TEACHING, RESEARCH OR MEDICAL PRESENTATION

I understand that videocassettes will be made of my child while he/she is participating in this study. I understand that data will be extracted from the videocassette for research purposes.

By signing this document I hereby consent to and authorise the use and reproduction of the videotapes taken of my child during his/her participation in this research project for the purpose of teaching, research presentation, or medical presentation with the understanding that the identity of my child will remain confidential. I understand that videotapes taken of my child will remain in a locked filing cabinet in the Motor Control Lab at the University of Ottawa.

I understand that the individuals who see the videotape of my child will not be told my child's name.

I understand that I can ask to view the video and decide, without fear of reprisal, not to let people other than the researchers directly involved in the research project, see the videotape made of my child reaching. If I do not want other people to see the video, I will tell one of the researchers.

DATE:

PARENT'S NAME (please print):

PARENT'S SIGNATURE:

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INFORMED CONSENT

(Participant)

Posture Control in Children

We are interested in finding out how you keep your balance when you reach for things. We are going to ask you to stand with your eyes open on a normal floor. When you hear a beep reach as fast as you can and hold you arm out straight until you hear another beep. We will measure your muscles with little plastic pieces we tape on before you start reaching. We will videotape you while you are reaching.

If you have any questions about what we want you to do, you can ask us at any time. If you get tired while you are doing the reaches, you can tell us and we will stop while you rest. If you wish to stop, you just have to tell your parents or us.

If you want to do the reaches, write your name on the line.

DATE:

MY NAME (print):

MY SIGNATURE:

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Appendix B

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Table 1

Postural Muscle Onset Latencies Relative to Movement Onset

Muscle		SS	df	MS	F	Sig.
		Anticipatory				
Right Erector Spinae	Between	1,406.271	1	1,406.271	4.103	0.059
	Within	5,826.613	17	342.742		
	Total	7,232.884	18			
Right Hamstrings	Between	58.961	1	58.961	0.29	0.597
	Within	3,655.202	18	203.067		
	Total	3,714.164	19			
Left Erector Spinae	Between	246.788	1	246.788	0.567	0.464
	Within	6,090.158	14	435.011		
	Total	6,336.946	15			
Left Hamstrings	Between	26.840	1	26.840	0.06	0.81
	Within	7,170.083	16	448.130		
	Total	7,196.923	17			
		Accompaniment				
Right Erector Spinae	Between	805.490	1	805.490	4.633	0.051
	Within	2,260.383	13	173.876		
	Total	3,065.873	14			
Right Hamstrings	Between	41.113	1	41.113	0.277	0.613
	Within	2,260.383	8	148.427		
	Total	3,065.873	9			
Left Erector Spinae	Between	12.087	1	12.087	0.056	0.818
	Within	2,166.817	10	216.682		
	Total	2,178.905	11			
Left Hamstrings	Between	56.753	1	56.753	0.39	0.541
	Within	2,326.238	16	145.390		
	Total	2,382.991	17			

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Table 2

Postural Muscle Onset Latencies Relative to Focal Muscle Onset

Muscle		SS	df	MS	F	Sig.
Anticipatory						
Right Erector Spinae	Between	1374.252	1	1374.252	7.566	0.016
	Within	2542.98	14	181.641		
	Total	3917.232	15			
Right Hamstrings	Between	29.243	1	29.243	0.056	0.816
	Within	9438.647	18	524.369		
	Total	9467.89	19			
Left Erector Spinae	Between	1275.483	1	1275.483	4.058	0.069
	Within	3457.49	11	314.317		
	Total	4732.973	12			
Left Hamstrings	Between	141702.296	1	141702.296	1.262	0.312
	Within	561558.63	5	112311.726		
	Total	703260.926	6			
Accompaniment						
Right Erector Spinae	Between	1787.449	1	178.449	1.2	0.292
	Within	2081.433	14	148.674		
	Total	2259.882	15			
Right Hamstrings	Between	27.572	1	27.572	0.112	0.743
	Within	3948.422	16	246.776		
	Total	3975.993	17			
Left Erector Spinae	Between	609.277	1	609.277	2.029	0.18
	Within	3602.776	12	300.231		
	Total	4212.052	13			
Left Hamstrings	Between	171.047	1	171.047	0.951	0.343
	Within	3057.349	17	179.844		
	Total	3228.396	18			

Table 3
Onsets of Changes in Vertical Ground Reaction Forces Relative to Movement Onset

Foot		SS	df	MS	F	Sig.
Anticipatory						
Right Foot	Between	5.361	1	5.361	0.036	0.852
	Within	2,691.449	18	149.525		
	Total	2,696.810	19			
Left Foot	Between	82.672	1	82.672	0.159	0.695
	Within	9,351.215	18	519.512		
	Total	9,433.887	19			
Total Body	Between	585.339	1	585.339	0.681	0.420
	Within	15,481.248	18	860.069		
	Total	16,066.587	19			
Accompaniment						
Right Foot	Between	21.342	1	21.342	0.276	0.606
	Within	1,394.417	18	77.468		
	Total	1,415.760	19			
Left Foot	Between	44.693	1	44.693	0.675	0.422
	Within	1,191.878	18	66.215		
	Total	1,236.571	19			
Total Body	Between	53.397	1	53.397	0.533	0.475
	Within	1,804.023	18	100.223		
	Total	1,857.420	19			
No Change						
Right Foot	Between	2.554	1	2.554	0.039	0.845
	Within	1,172.381	18	65.132		
	Total	1,174.935	19			
Left Foot	Between	5.835	1	5.835	0.039	0.845
	Within	2,673.524	18	148.529		
	Total	2,679.360	19			
Total Body	Between	32.539	1	32.539	0.259	0.617
	Within	2134.645	17	125.567		
	Total	2167.183	18			

Table 4
Probability of a Change in Vertical Ground Reaction Forces
Ocurring in a Given Time Period

Test	Chi-Square a,b	df	Asymp. Sig.
	Anticipatory		
Group	0.000	1	1.000
Right Foot	5.600	15	0.986
Left Foot	3.300	16	0.999
Total Body	16.400	13	0.228
	Accompaniment		
Right Foot	4.000	15	0.998
Left Foot	4.000	15	0.998
Total Body	16.400	12	0.174
	No Change		
Right Foot	24.000	10	0.008
Left Foot	15.100	12	0.236
Total Body	41.600	7	0.000

a) 0 cells (.0%) have expected frequencies less than 5. The minimum expected cell frequency is 10.0
b) 16 cells (100.0%) have frequencies less than 5. The minimum expected cell frequency is 1.3

Table 5

Probability of Muscle Activation in a Given Time Period				
Test	Chi-Square a,b	df	Asymp. Sig.	
Group	0.000	1	1.000	
Anticipatory				
Right Erector Spinae	4.000	15	0.998	
Right Hamstrings	14.200	8	0.077	
Left Erector Spinae	8.600	12	0.737	
Left Hamstrings	8.800	11	0.640	
Accompaniment				
Right Erector Spinae	16.000	9	0.067	
Right Hamstrings	21.600	7	0.003	
Left Erector Spinae	20.500	8	0.009	
Left Hamstrings	4.000	15	0.998	

a) 0 cells (.0%) have expected frequencies less than 5. The minimum expected cell frequency is 10.0

b) 16 cells (100.0%) have frequencies less than 5. The minimum expected cell frequency is 1.3.

Table 6

Probability of Postural Muscle Activation
in a Given Time Period

Test	Chi-Square a,b	df	Asymp. Sig.
Group	0.000	1	1.000
	Anticipatory		
Right Erector Spinae	4.000	11	0.970
Right Hamstrings	6.400	11	0.845
Left Erector Spinae	21.600	12	0.042
Left Hamstrings	34.600	5	0.000
	Accompaniment		
Right Erector Spinae	2.400	15	1.000
Right Hamstrings	3.400	12	0.992
Left Erector Spinae	9.900	12	0.625
Left Hamstrings	6.400	10	0.781

a) 0 cells (.0%) have expected frequencies less than 5. The minimum expected cell frequency is 10.0

b) 12 cells (100.0%) have frequencies less than 5. The minimum expected cell frequency is 1.7.

Table 7
Total Body Intra-Subject Coefficients of Variation

	SS	df	MS	F	Sig.
Anticipatory					
Between	13.417	1	13.417	2.729	0.117
Within	83.581	17	4.917		
Total	96.998	18			
Accompaniment					
Between	4.133	1	4.133	2.826	0.111
Within	24.861	17	1.462		
Total	28.994	18			
Feedforward					
Between	5.690	1	5.690	2.556	0.128
Within	37.843	17	2.226		
Total	43.534	18			

Table 8		Post-Hoc Power Analysis		
Window	Muscle Onset Latencies	Sigma	Effect Size	Power
Relative to Focal Muscle Onset				
Anticipatory	Right Erector Spinae	14.90788	1.19706	0.8236
	Left Erector Spinae	21.88239	0.884369	0.6016
	Right Hamstring	44.78925	0.443849	0.2452
	Left Hamstring	16.02506	1.126984	0.7819
Accompaniment	Right Erector Spinae	21.57383	0.654149	0.4062
	Left Erector Spinae	21.6143	0.636615	0.3917
	Right Hamstring	15.40151	0.156493	0.0955
	Left Hamstring	22.23437	0.614934	0.03739
Feed Forward	Right Erector Spinae	46.59478	0.040347	0.0596
	Left Erector Spinae	58.81684	0.047435	0.0615
	Right Hamstring	43.28904	0.26889	0.1432
	Left Hamstring	53.58183	0.040685	0.0597
Relative to Movement Onset				
Anticipatory	Right Erector Spinae	19.30052	0.892722	0.6085
	Left Erector Spinae	24.47181	0.331401	0.1758
	Right Hamstring	22.28442	0.117122	0.0819
	Left Hamstring	21.7919	0.195944	0.1107
Accompaniment	Right Erector Spinae	15.84508	0.751652	0.489
	Left Erector Spinae	15.27261	0.133572	0.0874
	Right Hamstring	15.91832	0.260077	0.139
	Left Hamstring	16.48483	0.216562	0.1193
Feed Forward	Right Erector Spinae	26.11924	0.326962	0.1734
	Left Erector Spinae	26.50071	0.144524	0.0912
	Right Hamstring	16.51064	0.787976	0.5201
	Left Hamstring	27.07104	0.196158	0.1108

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Table 9 A-Priori Power Analysis

Effect Size	Alpha	Power	Total Sample Size	Group Size
0.5	0.05	0.95	176	88
0.5	0.05	0.85	118	59
0.5	0.05	0.75	88	44
0.5	0.05	0.65	68	34