THE EFFECT OF VISUAL FLOW ON INFANTS DURING CRITICAL PERIODS OF DEVELOPMENT A CROSS-SECTIONAL STUDY

HONORS COLLEGE THESIS

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ABSTRACT

Twenty-one children of varying experience with locomotion were studied in order to measure the changing influence of vision on postural control during development. To accomplish this task, the degree of vision-induced sway and the degree of muscular response organization at different ages were measured. Data analysis found that the magnitude and frequency of postural responses decrease with increased walking experience, and in adults no visually observable response can be detected. Furthermore, the emergence of stepping strategies and the ability to attenuate postural responses over successive trials increases with increased walking experience. In addition, latency of activation of the visually induced postural response is much slower (200-600ms) and more variable than the response associated with platform perturbations. Contrary to my hypothesis, the movement of the visual box did induce leg postural responses in infants who were unable to stand, including the youngest subject of age 5 mos. The latency of muscle response from selected trials appears to decrease with increased walking experience. However, high variability in muscle organization seems to persist throughout behavioral groups, although an ascending synergy of muscle response is apparent in the most experienced walkers.

INTRODUCTION

Few parents can forget "baby's first step." This memorable event is noteworthy to researchers as well as to loved ones because it marks the successful culmination of many more subtle processes which research is only beginning to uncover. Before an infant can walk, it must develop certain postural skills which provide the required stability. These skills are developed in a progressive fashion which allow the infant first to sit, then stand, then walk independently. Postural control is thought to be limited by two factors: 1) musculo-skeletal factors such as changes in body size and muscle strength, and 2) nervous system factors, namely the ability to control the physical state of the body and its orientation in space. This subconscious ability is known as "proprioception."

It is generally thought that there are three main proprioceptive components which are critical to postural control and equilibrium in humans. These are vestibular, mechanical, and visual proprioception. The vestibular[1] apparatus is located in the inner ear and is responsible for detecting the orientation and movement of the head in relation to the pull of gravity. A simple way to detect impairment of the vestibular system is to have an individual stand still with eyes closed. If the system is damaged or immature, the individual will sway and possibly fall. However, in some cases of vestibular impairment individuals will not fall, due to compensation from the second component, introduced above as mechanical proprioception. This component is responsible for the detection of joint angulation, muscle length, and pressure sensation. For example, when we shift our weight from one foot to the other, or flex our feet at the ankle, the information we receive from our feet is due to mechanical proprioception. In addition, this component also detects the orientation of body parts in relation to each other. For example, an individual with delayed or impaired mechanical proprioception would have difficulty touching her nose with eyes closed. The third component, and the focus of the proposed study, is visual proprioception. Vision helps to orient the body relative to its surroundings. For example, when we sway backward, our visual field flows forward. Objects in front of us look farther away. By swaying forward to compensate, our visual field returns to its normal position. Studies of infants who are blind from birth show that the emergence of postural control and locomotion is delayed either due to lack of motivational factors (i.e. the presence of a nearby attractive object) or the inability to use visual cues for orientation (Fraiberg, 1977).

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[1] Vestibular: (Vestibule = 'cavity' or 'space') referring to the oval cavity in the bony labyrinth of the inner ear which plays an important function in equilibrium.

At some point, infants begin to coordinate a visual stimulus[2] with appropriate muscle responses, in order to keep their balance. This coordination has been shown to begin in the neck and trunk[3] of sitting infants who cannot yet stand (Bertenthal and Bai, 1987). The point in development when vision stimulates the postural responses in the leg is of special interest in the present study.

DEVELOPMENTAL RESEARCH

In 1974, a study by Lee and Aronson was the first to show that of the three proprioceptive components, the visual system is the dominating factor in infants who have just learned to walk (13-16 months old). In this study, newly standing infants were tested for responses to conflicting postural cues from the three proprioceptive systems. By using a small "movable room" consisting of three walls and a ceiling, the infant's visual field could be altered without affecting mechanical or vestibular inputs. (See Fig. 1). While the infant was standing on an immobile surface and facing the rear wall, the room was moved toward or away from the infant. This movement created the visual effect of falling although in actuality the child had not moved. Thus, the visual inputs indicated loss of balance, while the vestibular and mechanical inputs indicated stability. The study hypothesized that if vision is dominant in controlling posture at this age, the subjects would respond to the visual cues by activating appropriate muscles for the regaining of balance. Specifically, if

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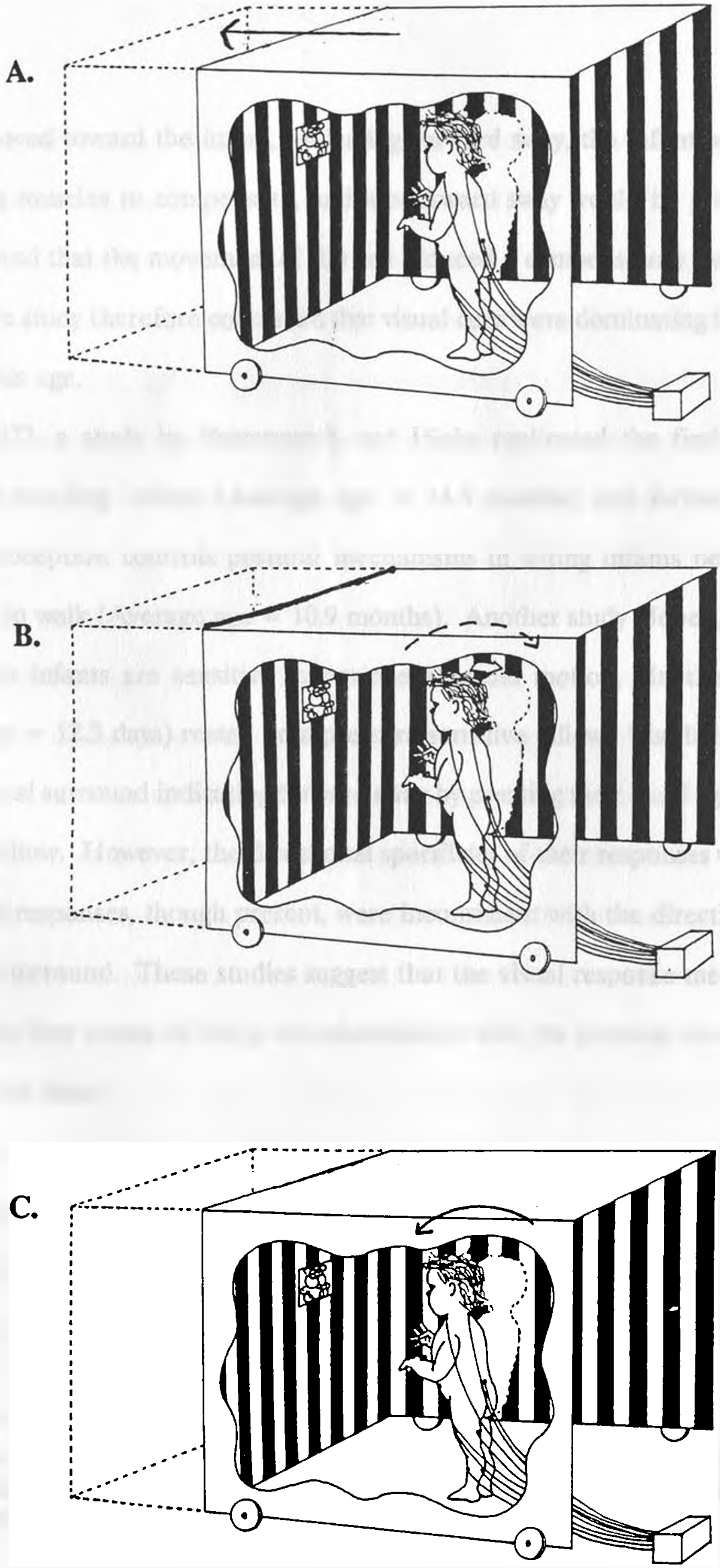
[2] Visual stimulus: In this case, the visual stimulus is the movement detected by our eyes which indicates that our center of balance is changing. For example, when we fall forward, our "visual field" flows backward. Thus, changes in our visual field stimulate our response to try to regain balance.

[3] Trunk - the central body region; uses abdominal and back muscles for postural support.

FIGURE 1

Figure 1. Depiction of the visual room and the expected sway pattern of a child during an AWAY Trial. A) The visual room moves away from the child. B) The child perceives that he or she is falling backward, indicated by the dashed arrow. C) The child compensates for the perceived sway by activating the anterior muscles to produce an actual forward sway, indicated by the solid arrow.



the room moved toward the infant, indicating forward sway, the infant would activate the posterior leg muscles to compensate, and a backward sway would be produced. Analysis of results found that the movement of the box induced a compensatory sway[4] in 82% of the subjects. The study therefore concluded that visual cues were dominating factors in postural control at this age.

In 1977, a study by Butterworth and Hicks replicated the findings by Lee and Aronson on standing infants (Average age = 14.9 months) and further concluded that visual proprioception controls postural mechanisms in sitting infants before the subjects had learned to walk (Average age = 10.9 months). Another study (Jouen, 1988) has shown that newborn infants are sensitive to peripheral visual motion. In this case, neo-nates (Average age = 12.3 days) rested on a pressure sensitive pillow. The babies responded to a moving visual surround indicating forward sway by pressing their head against or releasing if from the pillow. However, the directional specificity of their responses was not accurate. That is, their responses, though present, were inconsistent with the direction of movement of the visual surround. These studies suggest that the visual response mechanism which is present in the first weeks of life is not coordinated with the postural control system until several months later.

More recent studies have shown that the compensation response invoked by the visual system becomes more efficient and systematic over the latter half of the first year (Bertenthal and Bai, 1987). In this experiment the moving room was again used and responses of sitting infants at 5, 7, and 9 months of age were measured. This study found

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[4] Sway - a term used to describe the movement of a standing subject when leaning forward, backward or to the side. Sway is used by the body to regain balance. Sway increases during instable situations.

that the postural response increased proportionally with age. This suggests that sensitivity to optic flow develops gradually over the first year of life.

In normal adults, postural sway is not induced by the moving room because the brain is able to draw from mechanical and vestibular inputs rather than the faulty visual inputs (Owen and Lee, 1986). However, when standing on a wooden beam, the same adult subjects did sway in a similar fashion to infants standing on a stable platform. This finding suggests that under normal conditions, adults rely on mechanical rather than visual proprioception; when mechanical input is reduced, adults respond like infants in that they rely on visual input for stability.

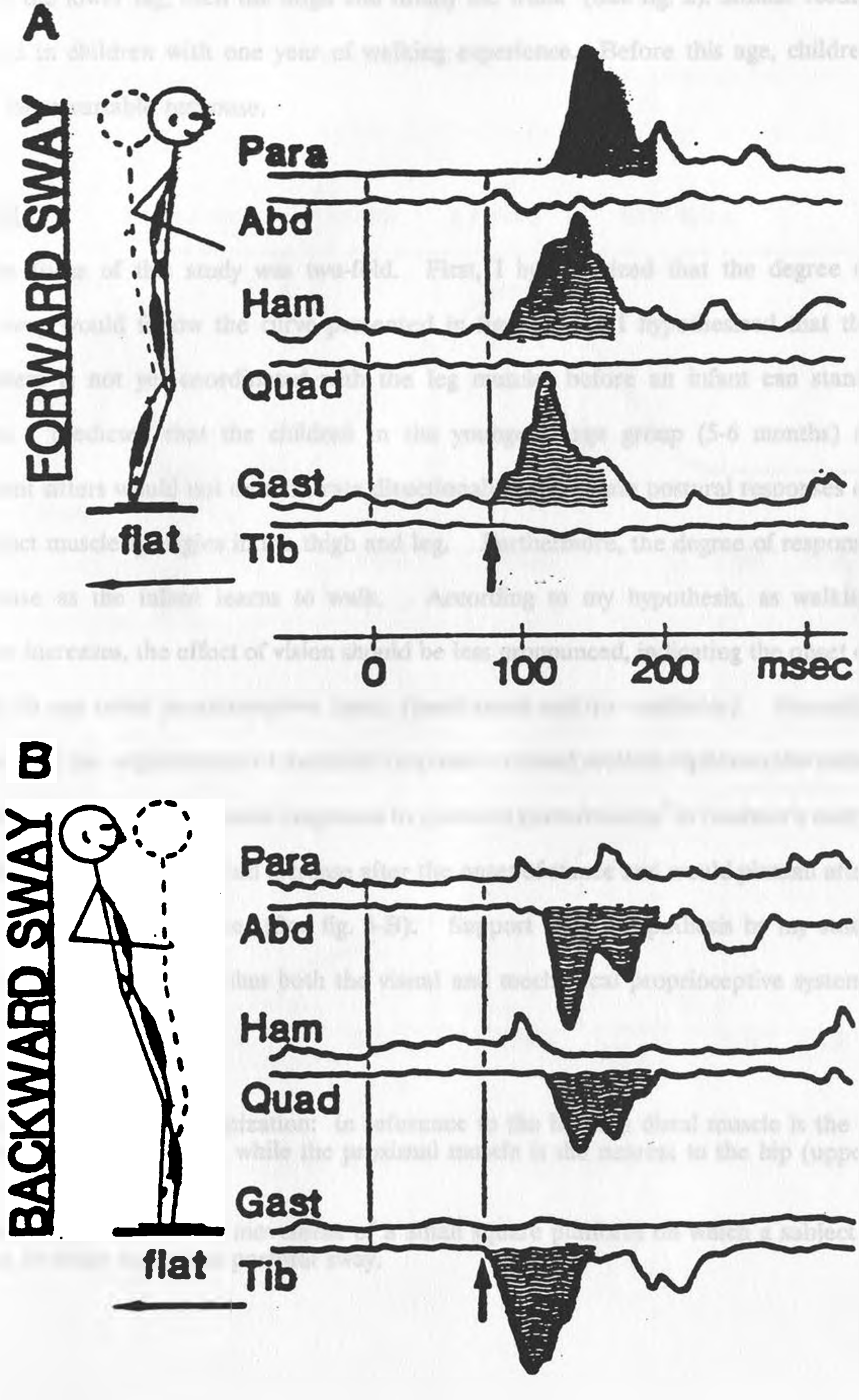
The experiments cited above describe only the sway responses to visual stimuli. None of these studies have characterized how individual muscle groups are responding. Do different muscle groups respond in a particular order in experienced walkers? If so, at what age does such organization begin to develop? Will the latency and magnitude of muscular response decrease with experience in walking? These are questions I will attempt to answer in the proposed study. Organization of muscle responses have been characterized in studies which look at the effect of mechanical inputs on stability (Nashner, 1977; Nashner and Woollacott, 1979). In these studies the subject stood on a movable platform which could shift horizontally or rotate about a horizontal axis. Shifting the platform in the forward direction caused the subject to first sway backward and then to activate particular muscles to compensate for the shift. The responses were recorded using electromyogram electrodes[5] placed on the leg and trunk. The studies concluded that adults first activate the

[5] Electromyogram electrodes - wires placed on the skin surface in order to measure how soon the muscle responds (onset latency), and how much of a response is given (magnitude).

FIGURE 2.

PLATFORM PERTURBATION SHOWING
ORGANIZATION OF MUSCLE RESPONSES IN ADULTS

KEY: Para = Paraspinal (back)
Abd = Abdominal
Ham = Hamstrings
Quad = Quadriceps
Gast = Gastrocnemius
Tib = Tibialis Anterior



muscles of the lower leg, then the thigh and finally the trunk (See fig. 2). Similar results were found in children with one year of walking experience. Before this age, children display a more variable response.

PURPOSE

The focus of this study was two-fold. First, I hypothesized that the degree of postural sway would follow the curve presented in figure 3-A. I hypothesized that the visual system is not yet coordinated with the leg muscles before an infant can stand. Therefore, I predicted that the children in the youngest age group (5-6 months) of independent sitters would not demonstrate directionally appropriate postural responses or have distinct muscle synergies in the thigh and leg. Furthermore, the degree of response will increase as the infant learns to walk. According to my hypothesis, as walking experience increases, the effect of vision should be less pronounced, indicating the onset of the ability to use other proprioceptive inputs (mechanical and/or vestibular). Secondly, I proposed that the organization of muscular response to visual motion replicates the distal to proximal organization[6] of muscle responses to platform perturbations[7] in Nashner's study. The degree of organization would increase after the onset of stance and would plateau after one year of walking experience (See fig. 3-B). Support of this hypothesis by my study would lead to the conclusion that both the visual and mechanical proprioceptive systems

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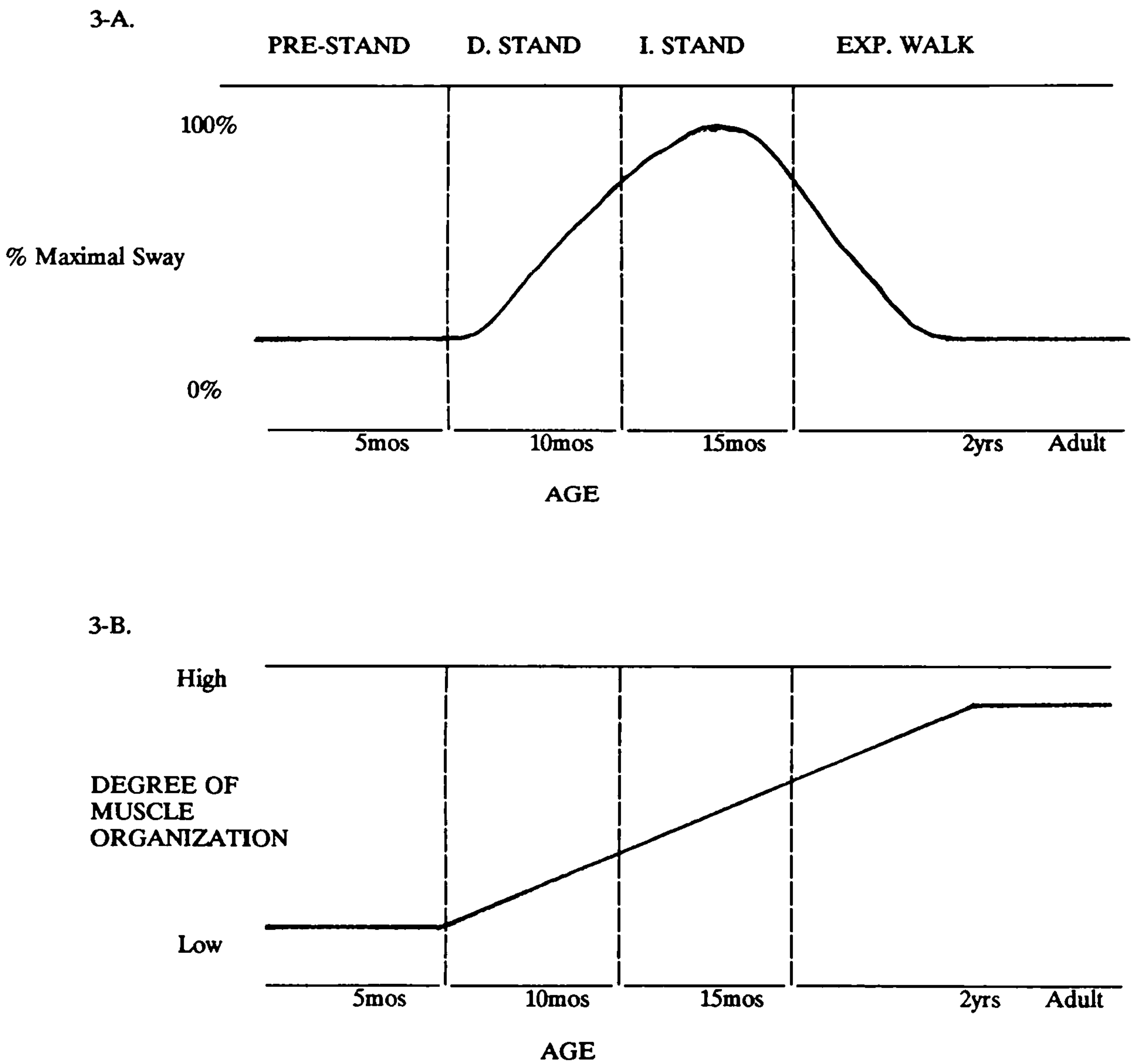
[6] Distal to proximal organization: in reference to the hip, the distal muscle is the one farthest away (lower leg), while the proximal muscle is the nearest to the hip (upper leg).

[7] Platform perturbation: movement of a small square platform on which a subject is standing in order to induce postural sway.

Figure 3.

HYPOTHESES



converge at some point to activate the same fixed set of muscular responses. If disproven, one could suggest that two separate systems are responsible for the postural responses by visual versus mechanical proprioception.

Subjects. The study sample included a total of 21 child subjects, with an additional control group of three adult subjects. The children were selected and grouped according to four different experience categories that correspond with the emergence of specific developmental skills: independently sitting (IS), pulling to stand (PS), newly walking (NW - having less than three months walking experience), and experienced walkers (EW - over one year of walking experience). This latter group was later subdivided into two age groups: EW1 (2-3.5 year olds) and EW2 (4-6 year olds). This was done to see if the 4-6 year olds displayed longer onset latencies or increased variability in comparison to the EW1 2-3.5 year olds as seen in earlier platform perturbation studies (Shumway-Cook and Woollacott 1985; Forssberg and Nashner 1982). A summary of the subject pool is provided in Table 1. Subjects were recruited from the community through day care centers, churches, and the Psychology department data base at the University of Oregon. Toys were available to the children, and all efforts were made to make the child as comfortable as possible with the lab setting. All participation was completely voluntary and if the children became fussy or upset, the trials were stopped immediately.

Table 1. SUMMARY OF SUBJECT POOL

Category	# of Subjects	Mean Age +/- S.D.
I.S.	3	6.5 +/- 1 mos.
P.S.	5	8.8 +/- 0.8 mos.
N.W.	5	12 +/- 1 mos.
E.W.1	3	3 +/- .5 years
E.W.2	5	4.9 +/- .9 yrs
Adult Control	3	27 +/- 5 years
	Total 24	

Apparatus. The apparatus used in this experiment is similar to the "moving room" used by Butterworth and Hicks (1977) and by Bertenthal and Bai (1987). The room is small (1.2m x 1.2m x 1.0m) with the floor and one wall removed (See Figure 1). The room is mounted on small wheels which allow the forward and backward movement required for this study. The interior is painted white with vertical green stripes to enhance the perception of visual movement. Movement is limited to 60 cm by markings placed on the floor at appropriate positions. The experiment is conducted by two experimenters: one moves the box manually while the other records data on an IBM compatible computer. The mean velocity of the box movement during each trial was found to be 0.48 m/s (SD=0.03 m/s).

There are two windows in the box. The smaller one (16cm x 16cm) is located on the front wall and allows the first experimenter to peer through in order to direct the subject's gaze prior to each trial. The larger window (60cm x 90cm) is located on the left side wall. The window is covered with special one-way glass that becomes a mirror interiorly when the inside is illuminated by a 60 watt light attached to the front window, and another attached at the box entrance. This feature allows the infant to be videotaped by a video camera mounted on a platform outside the box.

An accelerometer is used to quantify the movement of the box. This device is attached to the outside of the box and is wired to the data computer.

In order to identify body segment lengths, markers (white stickers) are placed at the ankle, knee, center of mass[8], and shoulder. The distance between these markers as well as body height is then recorded. The movement of these markers in space can be transformed from the video camera coordinates into x and y coordinates for graphing purposes. By this method, the angle of postural sway can be quantitatively measured.

Finally, a total of six electromyogram (EMG) electrodes were placed on the infant in order to measure the responses of six major muscle groups involved in postural control. These include the tibialis anterior (shin), gastrocnemius (calf), quadriceps (front of thigh), hamstrings (back of thigh), trunk extensors (back), and abdominal muscles.

Procedure. During the experiment each child faces the front wall of the box while standing on a point indicated on the floor. Infants who were incapable of independent stance were supported lightly by a parent from behind. Should a loss of balance occur, the parent was then able to give support to prevent their child from falling. In some cases, in order to calm the infant, the parent or a sibling sat in front of the infant rather than behind. Every child in the study was accompanied by a parent who was near them at all times. During

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[8] The location of the center of mass is computed to be .52h, where h is the height of the infant.

the sessions for the adult control subjects, the visual box was elevated and placed upon two long tables placed side by side two feet apart so that the subject could stand freely inside the room. The box could then be pushed along the table top, toward and away from the subject. In this way, and the experiment could be continued following the same protocol as for the younger subjects.

After a one second baseline of quiet stance and forward gaze had been reached, the first experimenter moved the box a distance of 0.6m (2 feet). The direction of movement (toward and away from subject) was alternated. The second experimenter recorded EMG data on the computer after each trial. The next trial began as soon as the subject had re-established a baseline stance. The video-camera was activated during the entire session.

Design. Each subject was exposed to an equal number of trials for movement in the forward and backward direction. The first trial for each child was randomly assigned to be forward or backward in direction. After the first trial, the direction was alternated until a total of at least 8 trials, four in each direction, had been completed. This number was chosen because other experiments (Bertenthal and Bai, 1987) had obtained statistically significant data with the same number of trials.

Assessment.

EMG DATA: The EMG data were quantitatively assessed in two ways, using the Datapac computer program. First, for each trial the onset time of each of the six muscle groups was coded with respect to the onset time of the initial movement of the box. A response was only recorded if the muscle burst was greater than the baseline activity. If a muscle had no response, or if the particular electrode was faulty, a special code was recorded to indicate this. From a table made from this information, the average onset latency and frequency of onset could be determined. Secondly, the magnitude in volts of every coded burst was recorded with respect to baseline voltage. This information was useful in determining relative strength of response and degree of adaptation across trials.

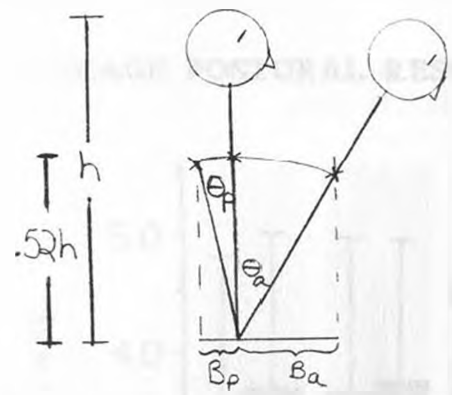
KINEMATICS: The video tape data was assessed both qualitatively and quantitatively. To assess the trial qualitatively, each trial was scored on a scale from 0 to 5 in terms of baseline position, degree of support given by the parent (applicable only to the youngest two groups, IS and PS), and extent of response by the subject. To assess baseline, two factors, body position, and focus of gaze was considered. A score of 5 signified a perfect stance and focus, while 0 indicated complete lack of attention, or excessive wiggling and turning. A baseline score of less than 3 disqualified the trial, as the response was difficult to associate with the movement of the box. If the infant was being supported, a score of five indicated a high, restrictive, amount a support given usually around the trunk, while 1 indicated light support such as being held by one hand. Finally, a response score was given according to the following guidelines:

5 = fall, or if supported, a maximal sway which would have resulted in a fall.
4 = two or more steps were taken before balance was regained, or the infant was barely able to prevent a fall.
3 = one step was taken, or a significant sway occurred.
2 = no steps were taken, but sway could be easily perceived
1 = very slight sway perceived
0 = no movement

On the basis of these 3 behavioral scores, as well as qualitative notes regarding type of flexion or extension of movements, a concise description of the trial could be obtained.

The quantitative portion of the video assessment is two-fold. First, by measuring the number of video frames that occur between the initiation of box movement and the subject's postural response and dividing by a conversion factor of 30 frames per second (The video camera operates at 30 Hz), the response time was measured. By comparing this data with the onset latency recorded from the EMG data, it was possible to approximate (within 66ms) the time delay between muscle activation and visible sway response. Secondly, using the Macintosh Video program, which captures video frames on the computer screen, the angle of sway response for each trial was computed for selected subjects from each group. Two frames were analyzed per trial. The first depicted baseline stance for which the initial angle of stance was measured between three points, the center of mass, the ankle, and the toes. The second recorded frame displayed the maximum angle of sway for the trial. The difference between the two angles was recorded as the degree of sway. These data procured from the video camera were used to assess postural sway as a percentage of maximal sway. The maximal degree of sway was computed by the following equation: $\sin\theta$ = base of support/center of mass. Theta (θ) is the maximal angle of sway the body can be displaced without falling (See fig. 4). The actual sway of the infants during each trial will be determined by measuring the angles between markers located on the ankle and side of body where the center of mass was located. According to the results of previous research, movement of the box toward the subject would be expected to produce posterior sway while movement of the box away from the subject should produce anterior sway (Lee and Aronson 1974).

Figure 4: Calculating Maximal Sway



Equation: $\sin\theta = B / .52\,h$
θ_p = Maximal angle of posterior sway
θ_a = Maximal angle of anterior sway
B = Base of support
h = Height of infant
.52h = Location of center of mass

RESULTS AND DISCUSSION:

KINEMATICS

Qualitative Video Scoring: All 24 subjects were individually scored per trial on a scale of 0 to 5 for magnitude of postural response (zero indicated no response, while a five indicated a maximal sway or fall). The scores for each behavioral group were then averaged and compared (See figure 5). The groups with the greater level of walking experience, EW1, EW2, and the adult group exhibited a marked decrease in magnitude of response. In fact, the adult group never showed sway. This suggests that walking experience leads to a decrease in visually dominated proprioception and an increased ability to follow mechanical and vestibular proprioceptive cues. This is further confirmed by results of frequency of non-zero responses across groups (See figure 6) which again demonstrates the ability of the older three groups to choose to completely ignore the visual stimulus caused by the box movement and remain stationary.

In order to determine whether subjects learned to attenuate their responses after several trials, the behavioral scores of response magnitude across trials were graphed for each subject in the NW, EW1, and EW2 groups (See figures 7, 8, and 9). The responses

AVERAGE POSTURAL RESPONSES AMONG BEHAVIORAL GROUPS

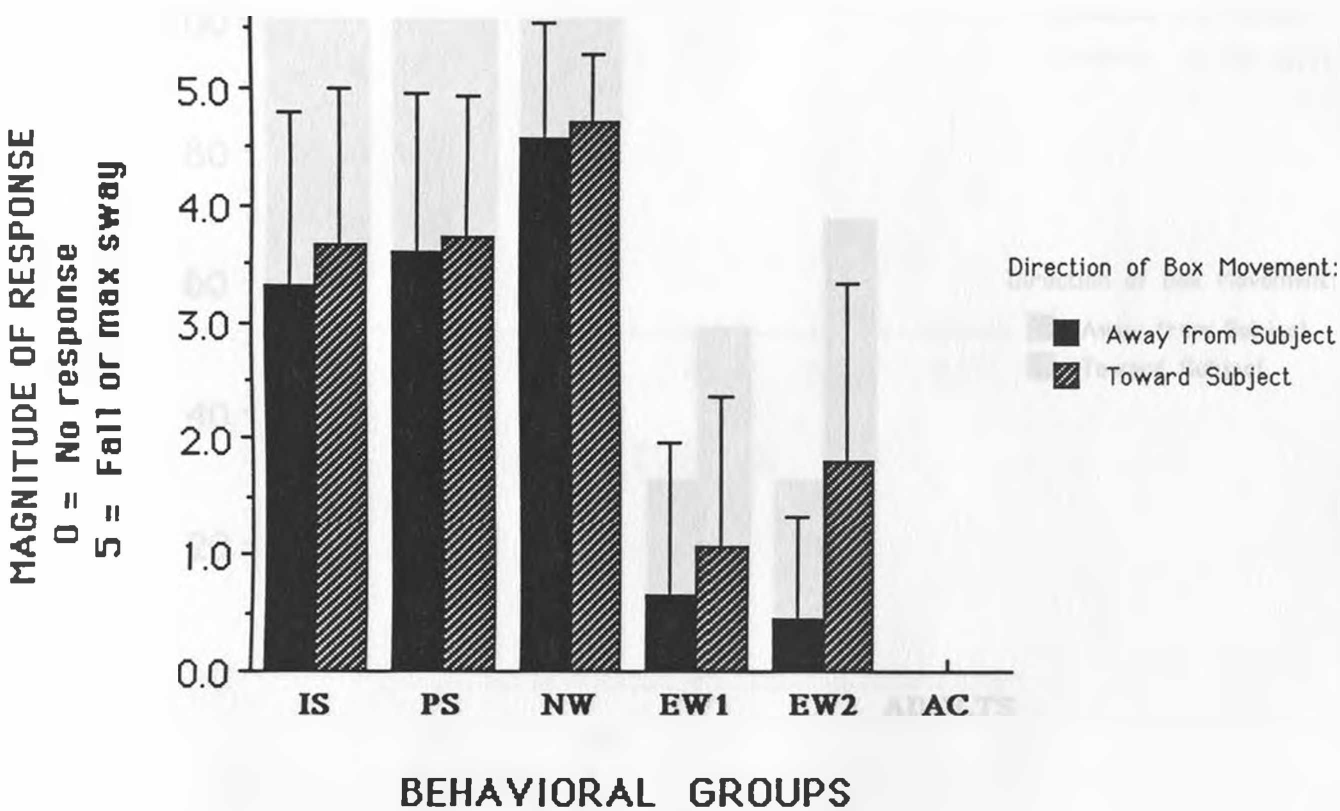


Figure 5. Postural responses of subjects were recorded from video tape data, and scored on a scale from 0 to 5 according to the following criteria: 0 = no response; 1 = slight sway, 3 = well-defined sway or a small step; and 5 = subject fell or would have fallen without the support of the parent.

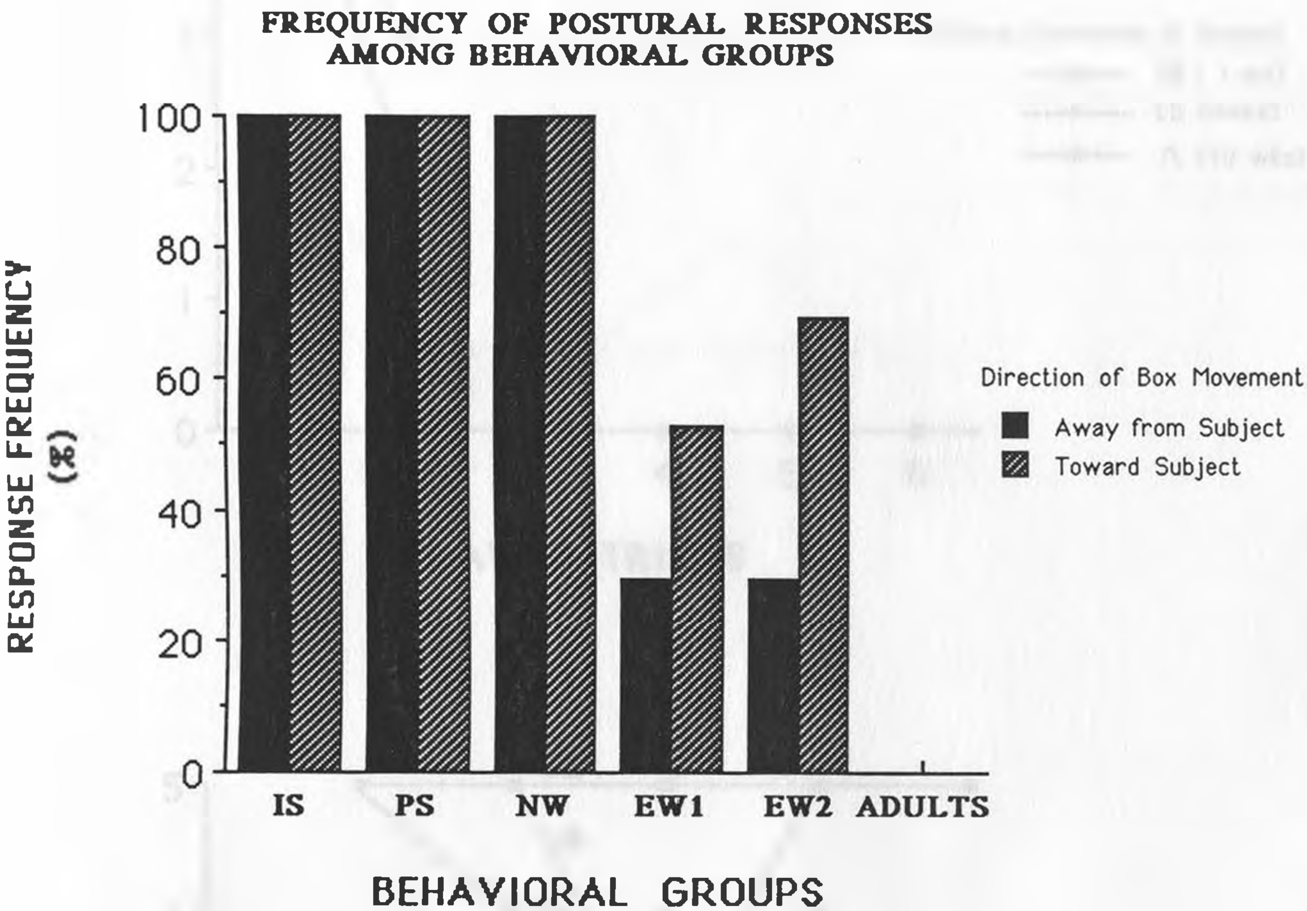
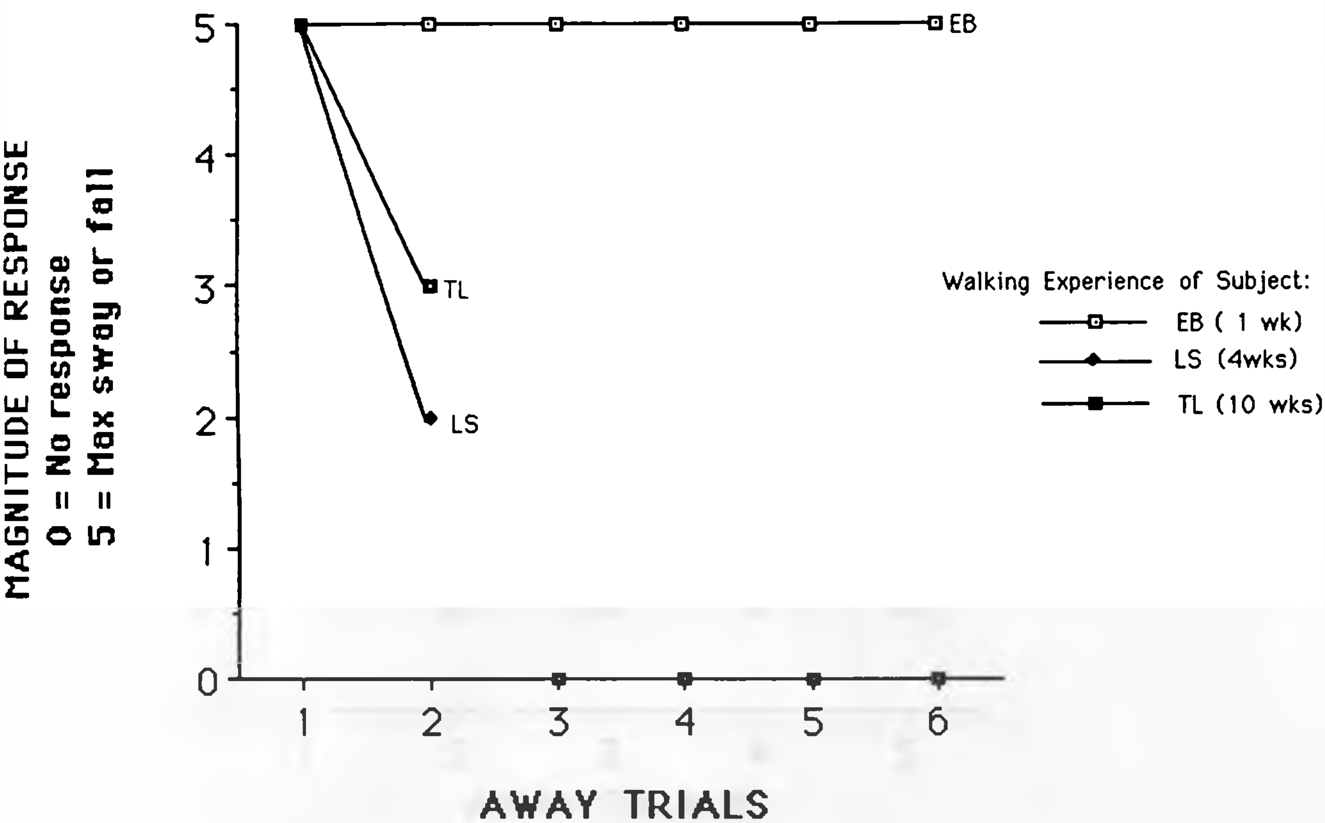


Figure 6. The frequency of postural responses from the video scoring were recorded as a percent of total trials taken for each group. The total number of usable trials for each group were: (AWAY) IS =10; PS = 20, NW = 12; EW1 = 17; EW2 = 27; ADULT = 10. (TOWARD): IS = 9; NW = 17; EW1 = 17, EW2 = 26, and ADULT = 11.

FIGURE 7

POSTURAL RESPONSES OF NEW WALKERS OVER SUCCESSIVE TRIALS
AGE GROUP: 11- 14 MOS



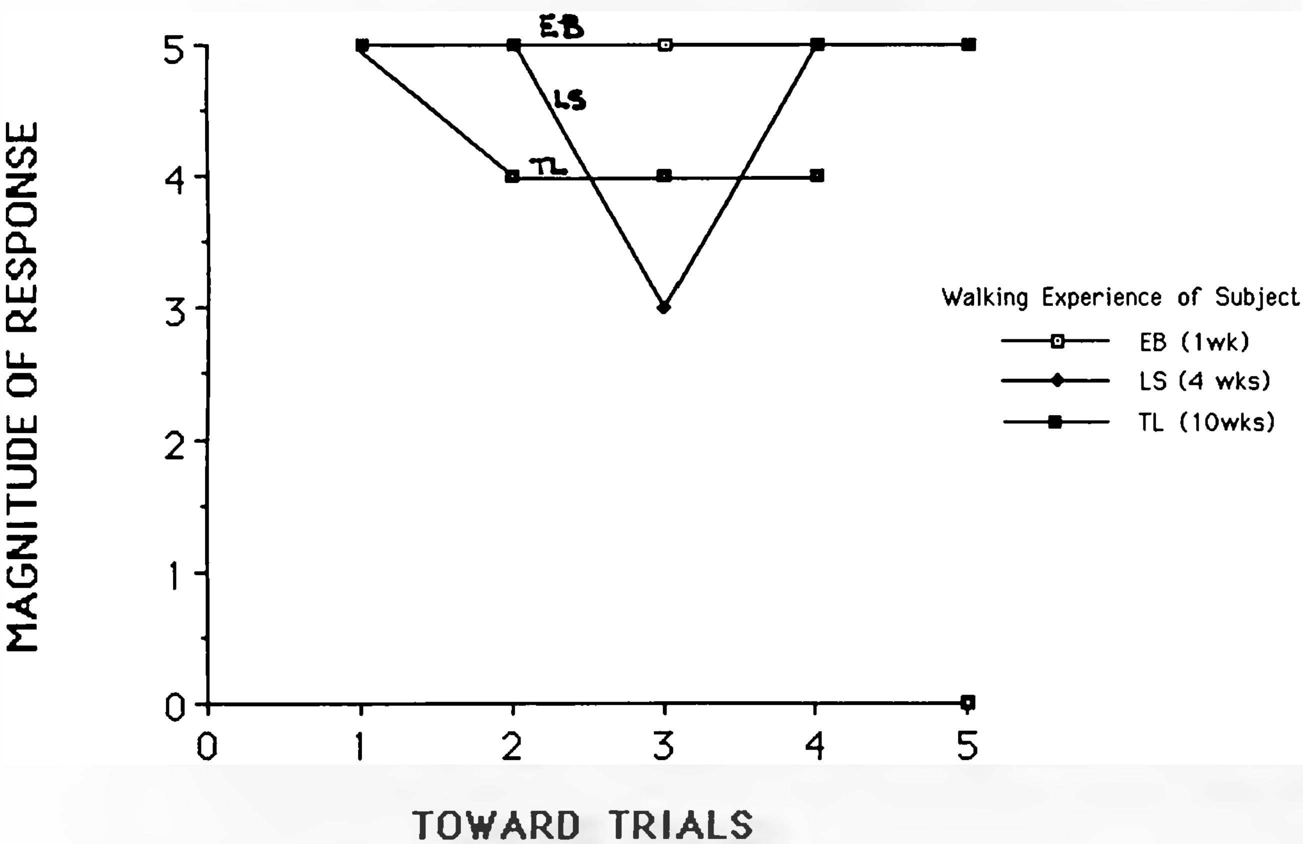
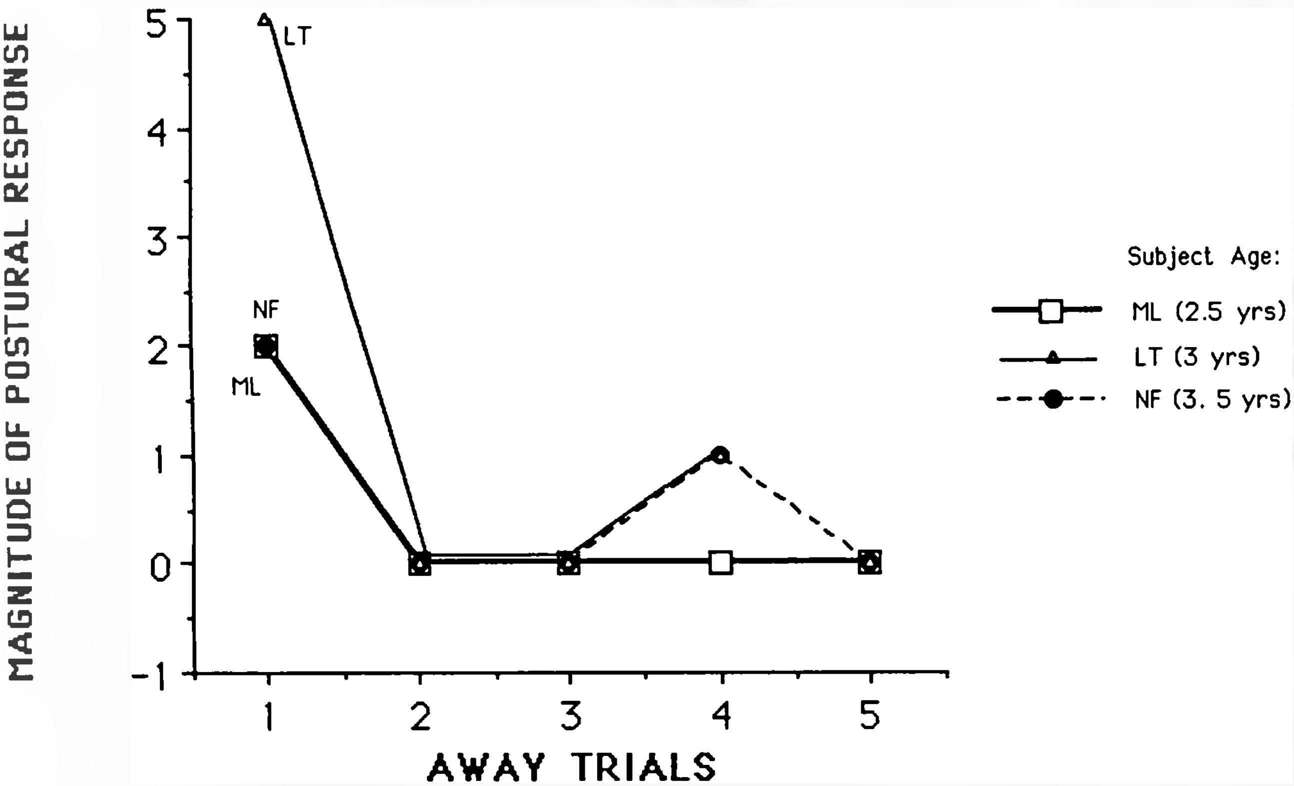


FIGURE 8

POSTURAL RESPONSES AMONG EXPERIENCED WALKERS ACROSS SUCCESSIVE TRIALS AGE GROUP: 2-3 YRS



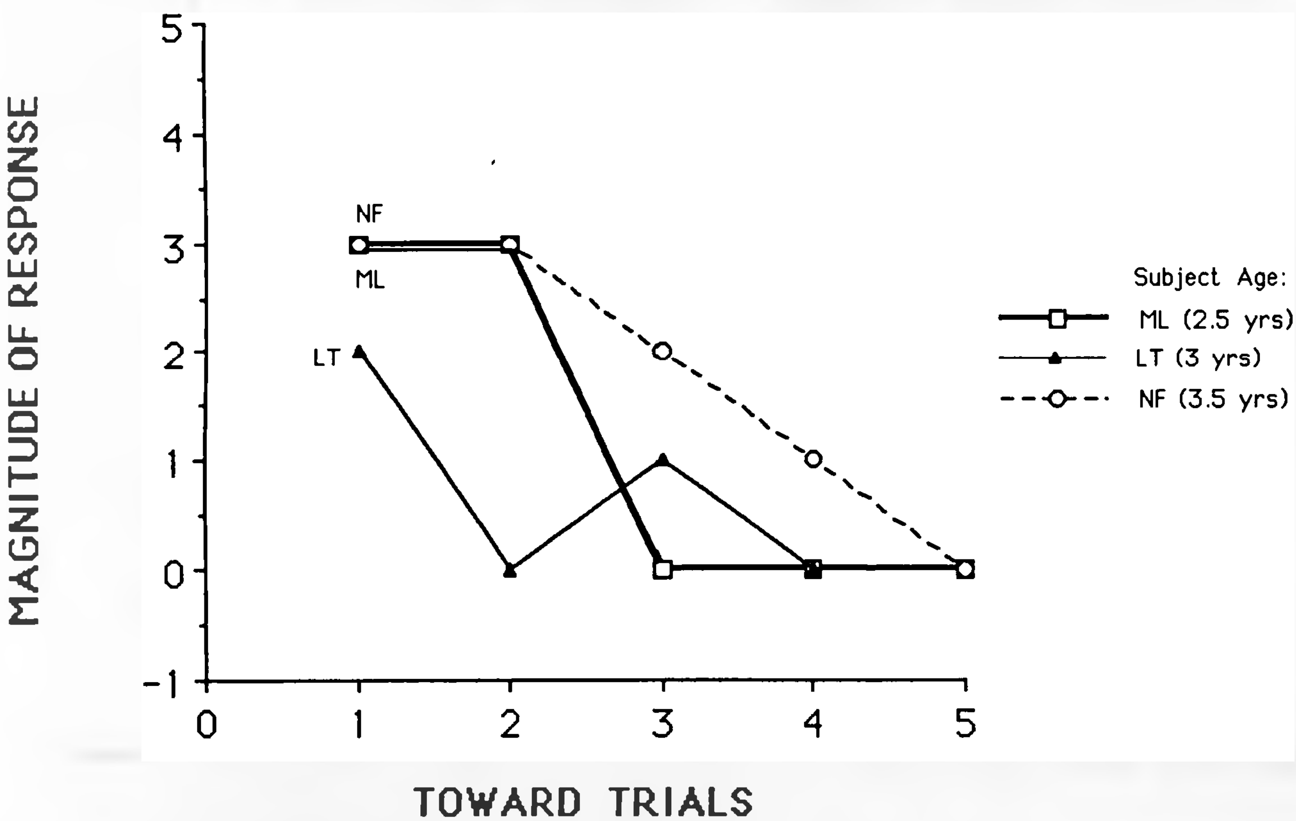
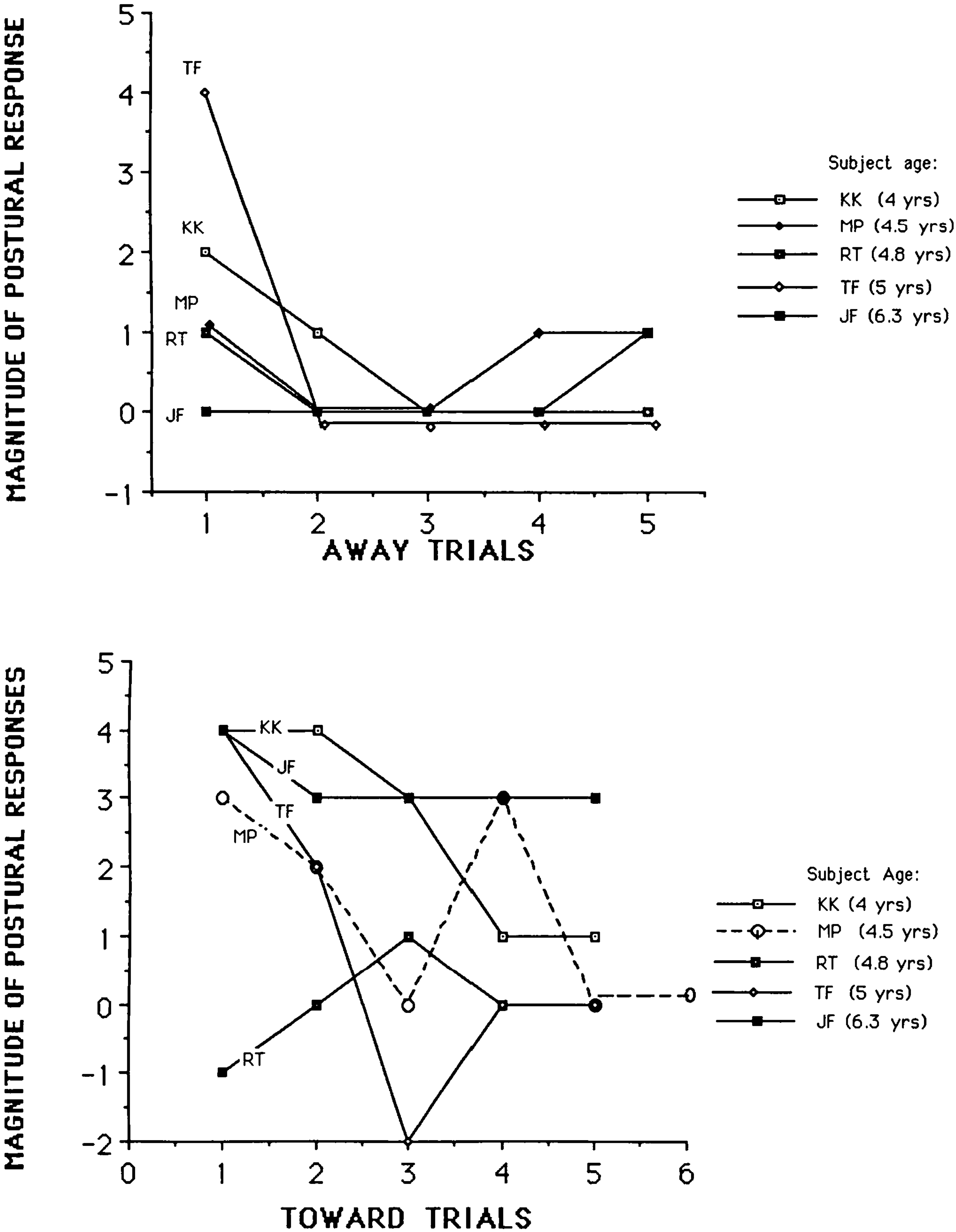


FIGURE 9

POSTURAL RESPONSES AMONG EXPERIENCED WALKERS ACROSS SUCCESSIVE TRIALS AGE GROUP: 4-6 YRS



(Negative values indicate an improper response, i.e. a movement in the forward direction during a Toward trial.)

for the new walkers all began at the maximum level (indicating a fall or maximum sway) and never fell below "2" for Away trials, and "3" for Toward trials. For the subject with just one week walking experience, maximum responses occurred for each of the twelve total trials with no indication of attenuation. This occurred despite the fact that this subject did have 6 mos of crawling experience and was therefor familiar with self locomotion. At 4 and 10 weeks of walking experience, it appears that some attenuation takes place, but only to a limited degree.

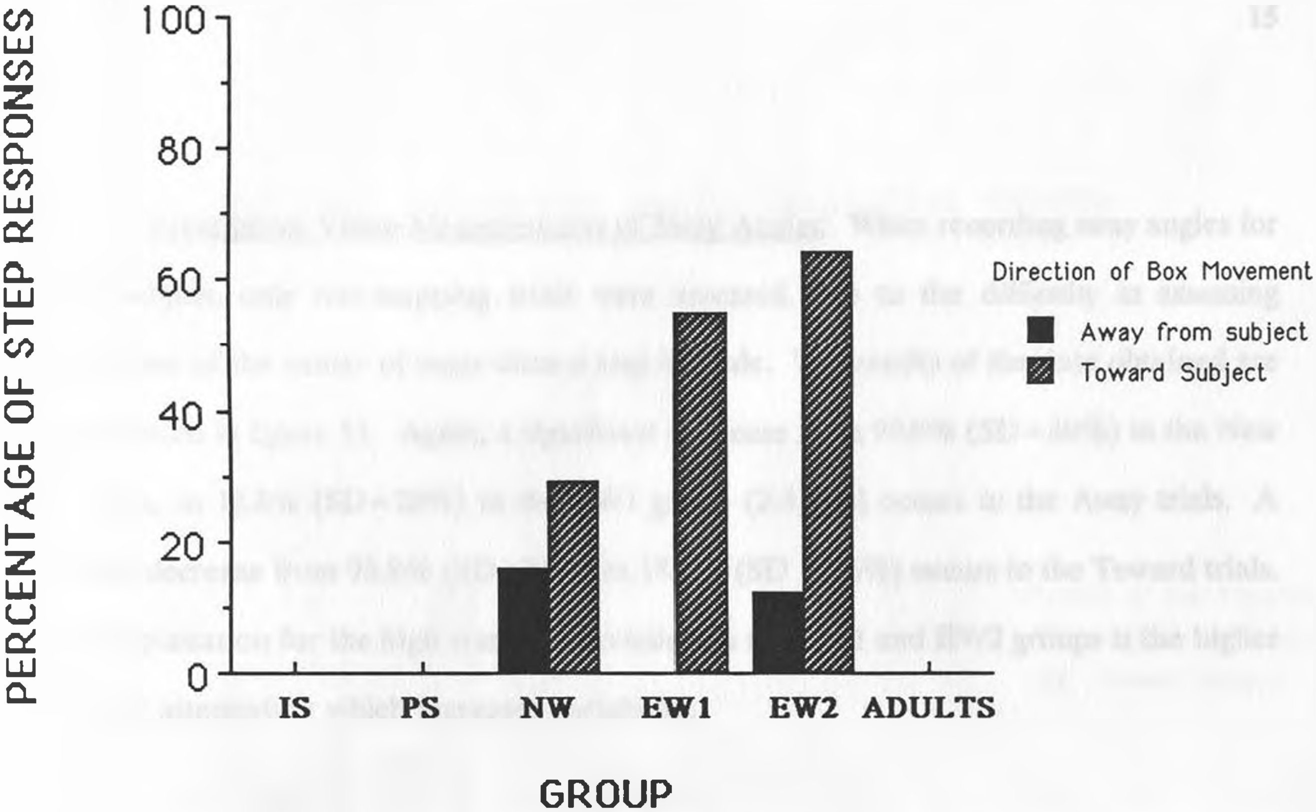
In contrast, all three subjects in the 2-4 yr group show marked degrees of attenuation in both directions. Each subject was able to lower his or her response to zero after one trial in the Away direction and after three trials in the toward direction. This suggests that children in this age group are able to switch from one proprioceptive mechanism to another after a small number of trials.

Remarkably, while the 4-6 year olds show a similar attenuation pattern to the 2-4 year olds for Away trials, the pattern of response for Toward trials is highly variable and even though some attenuation does occur in every subject, it is markedly decreased. Of particular note is the presence of "improper" responses in two of the subjects (RT and TF) denoted by negative numbers in figure 9B. Both subjects reach a zero response by the end of the session, but only after experiencing both positive and negative responses. Furthermore, this age group shows a significant preponderance of step responses during Toward trials (See fig. 10B). The oldest subject in the group (JF, age 6.3 yrs), steps backward in 100% of the Toward trials.

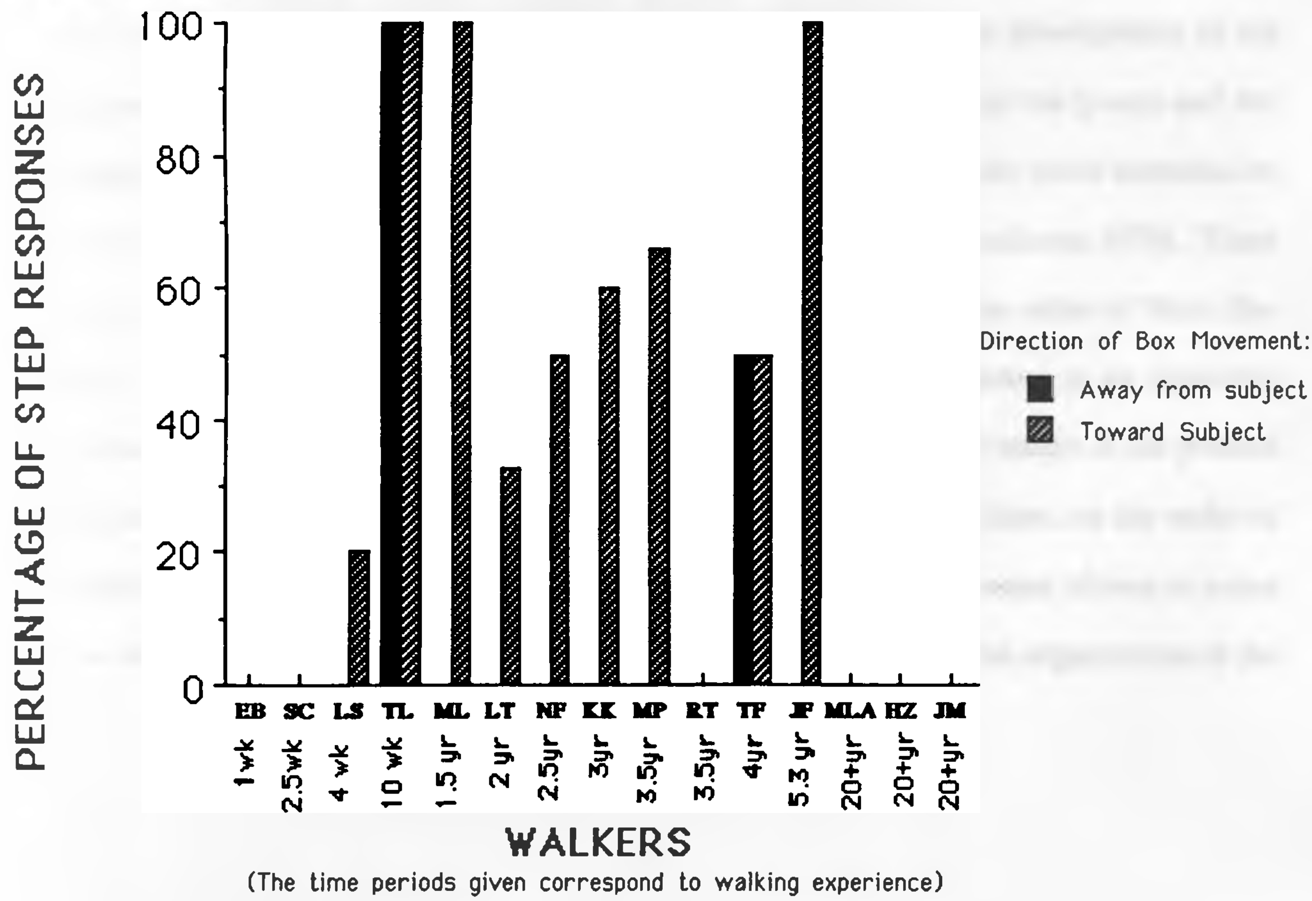
For the adult group, each of the three subjects displayed zero responses to the movement of the box in either direction, for the duration of the session.

FIGURE 10

THE EMERGENGE OF STEPPING STRATEGIES ACROSS BEHAVIORAL GROUPS



EMERGENCE OF STEPPING STRATEGY WITH WALKING EXPERIENCE



Quantitative Video Measurements of Sway Angles: When recording sway angles for each subject, only non-stepping trials were assessed, due to the difficulty in assessing movement of the center of mass when a step is made. The results of the data obtained are represented in figure 11. Again, a significant decrease from 90.6% (SD=30%) in the New Walkers, to 12.8% (SD=28%) in the EW1 group (2-3.5yrs) occurs in the Away trials. A similar decrease from 93.8% (SD=21%) to 18.3% (SD = 36%) occurs in the Toward trials. One explanation for the high standard deviation in the EW1 and EW2 groups is the higher level of attenuation which increases variability.

EMG ONSET LATENCIES: Average onset latencies of six muscle groups were computed for each group (See figure 12). These averages indicate that for the Toward trials, a significant decrease in muscle onset latency occurs with the development of the postural control system. In the away trials there is more variability across groups and the latency trend is not distinct. Previous research has characterized muscle onset latencies for responses to platform perturbations (Nashner, 1977; Nashner and Woollacott, 1979). These studies have shown onset latencies to occur in the distal muscle on the order of 90ms (See figure 2). In addition, a distinct and predictable muscle synergy occurs in an ascending fashion from the distal to the proximal muscle group. However, the results of the present study show that the onset latencies of the distal muscle occur much later, on the order of 200-600ms. This is visually confirmed by the video data which shows onset of sway to occur from 400-800ms after the movement of the box begins. In addition, the organization of the

AVERAGE POSTURAL RESPONSES AMONG BEHAVIORAL GROUPS
(Recorded as a Percentage of Maximum Sway Angle)

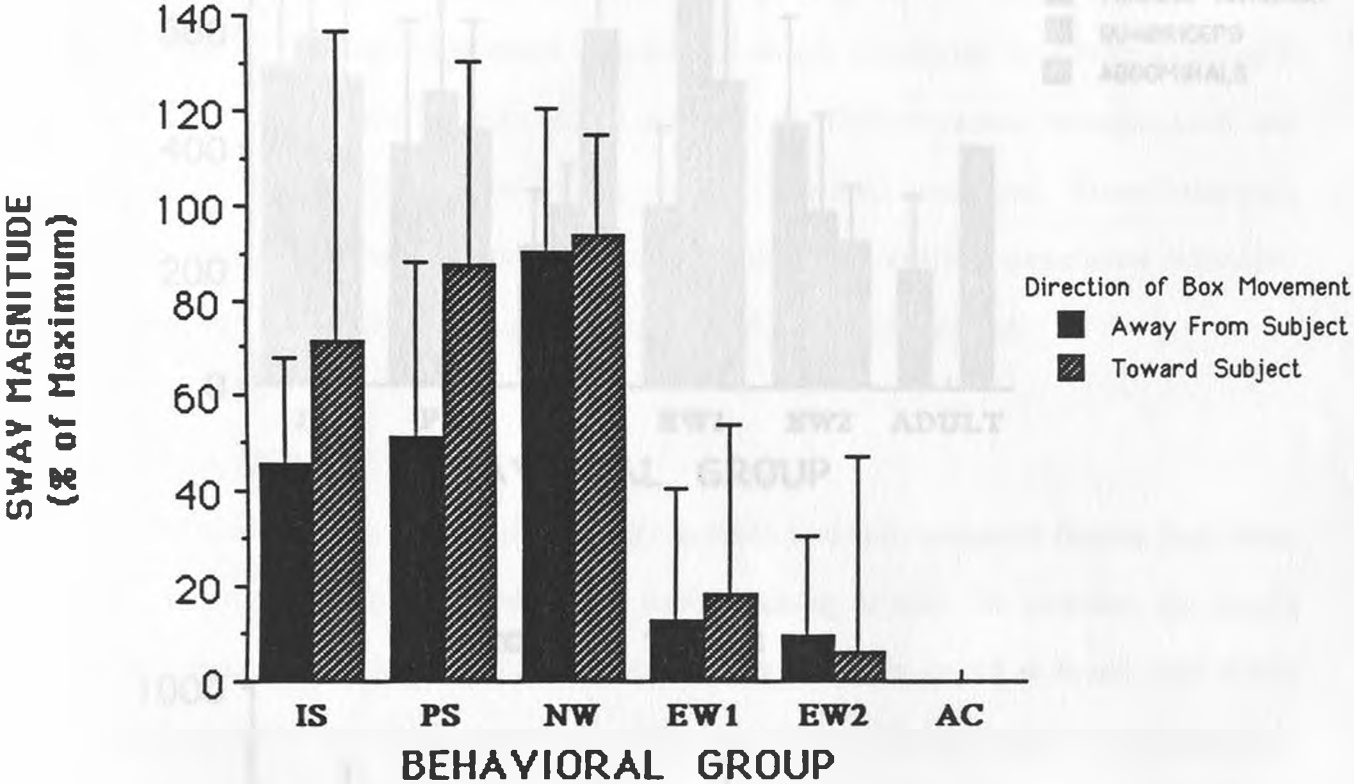
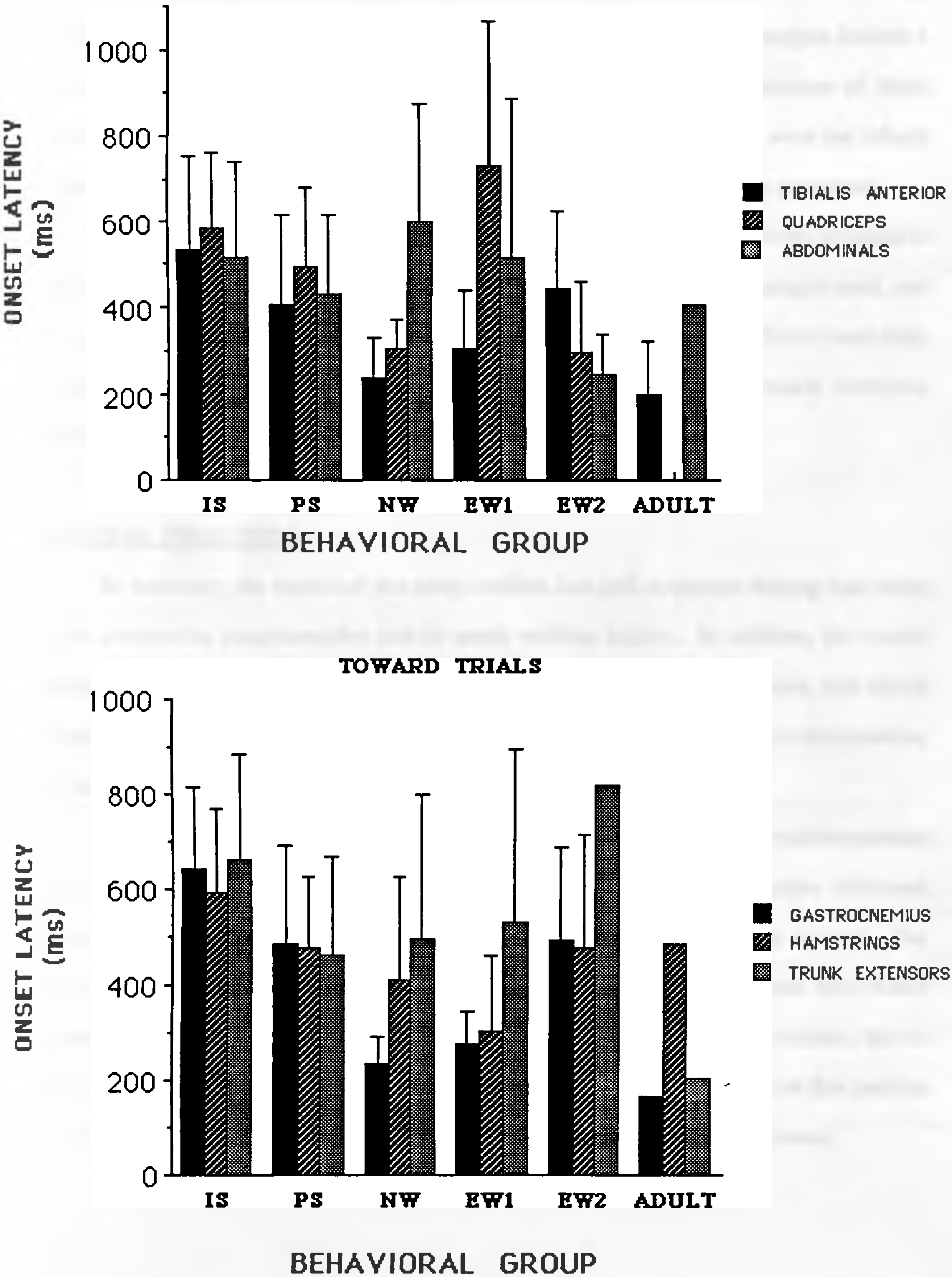


FIGURE 12

EMG ONSET LATENCIES AMONG BEHAVIORAL GROUPS

AWAY TRIALS



muscle response was highly variable. Examples of different muscular strategies include a proximal to distal organization, a strong trunk response without the assistance of distal muscles, and several other combinations of muscle groups. Significantly, even the infants in the youngest category displayed distinct muscular responses to the box movement.

EMG recordings of selected trials from a sample of subjects have been included in figures 13 to 16. These trials are the best examples of different muscle strategies used, and also provide information on onset latency of the first muscle to respond. From these trials as well, it appears that the onset latency decreases as walking experience increases. However, the variability of muscle strategies continues across groups.

GENERAL DISCUSSION

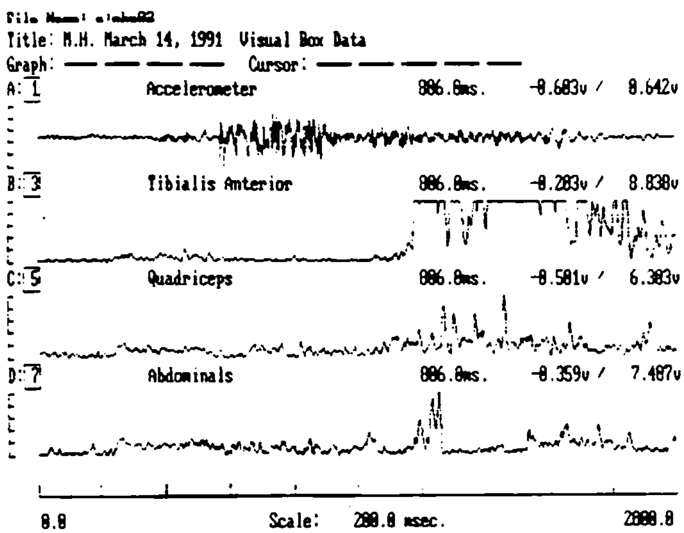
In summary, the results of this study confirm Lee and Aronson's finding that vision is the dominating proprioceptive tool in newly walking infants. In addition, the results obtained from the adult group in this study confirm, as Owen and Lee found, that adults do not respond to the visual movement of the box. From this framework of consistencies, the present study has further reached several significant findings.

First, infants as young as five months of age exhibit directionally appropriate postural sway. Subjects in the Independent Sitting and Pull to Stand categories displayed appropriate sway in one-hundred percent of the trials when standing with support. The presence of distinct muscle synergies in the leg, thigh, and trunk is evident from EMG recordings as early as 7 months (No EMG data was usable from the 5 mos subject, due to noise interference.), and is also present in the pull to stand subjects. Thus, the first portion of my original hypothesis which predicted low response at this age is disproven.

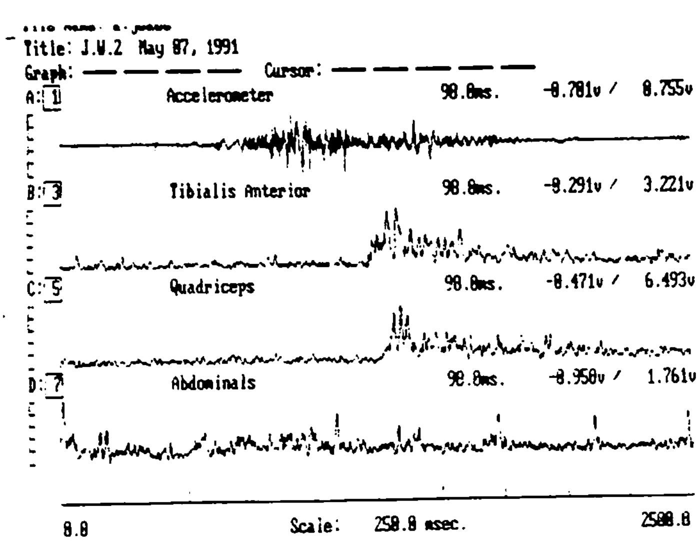
SELECTED ELECTROMYOGRAM RECORDINGS FOR INDIVIDUAL TRIALS DEPICTING MUSCULAR SYNERGIES AND ONSET LATENCIES

INDEPENDENT SITTERS

AWAY TRIALS

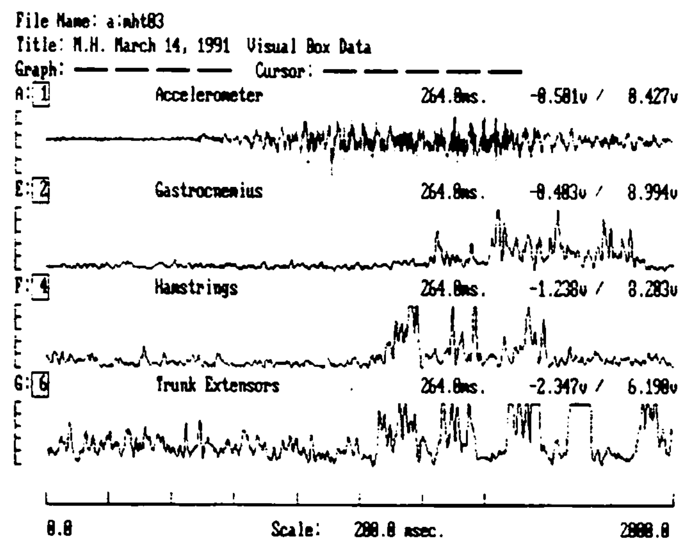


Muscle strategy: Q-TA-A Latency: 700ms

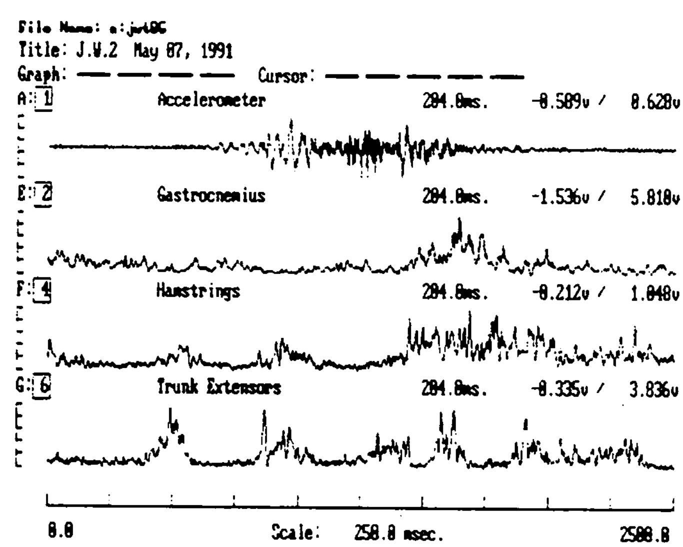


Muscle strategy: TA-Q Latency: 600ms

TOWARD TRIALS



Muscle strategy: H-TE-G Latency: 525ms

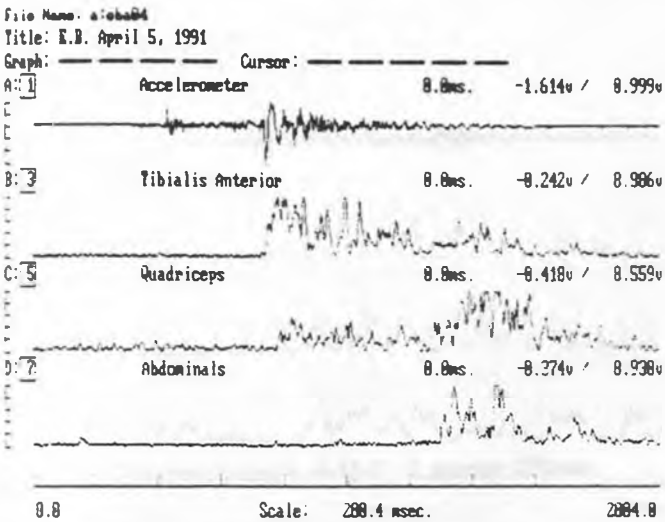


Muscle strategy: G-H Latency: 725ms

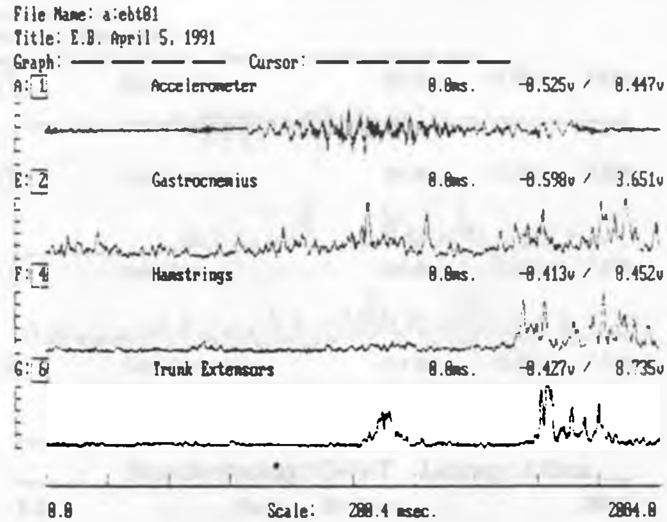
SELECTED ELECTROMYOGRAM RECORDINGS FOR INDIVIDUAL TRIALS DEPICTING MUSCULAR SYNERGIES AND ONSET LATENCIES

NEW WALKERS

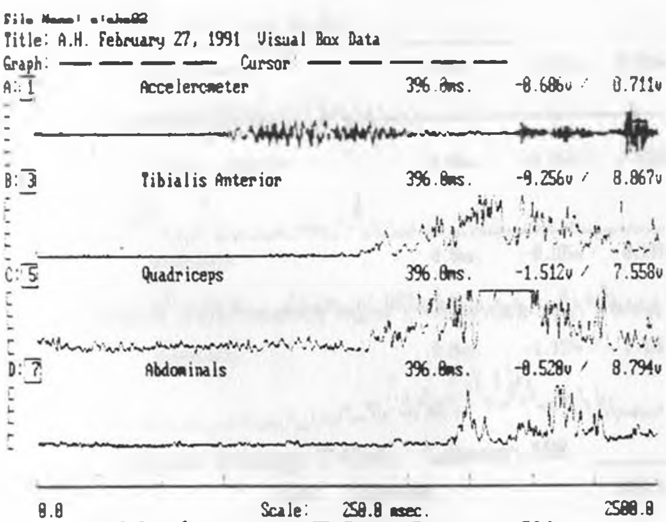
AWAY TRIALS | **TOWARD TRIALS**



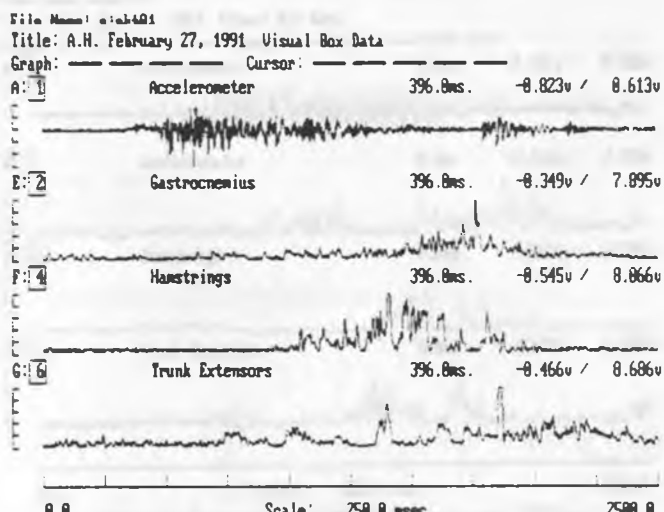
Muscle strategy: T-Q-A Latency: 300ms



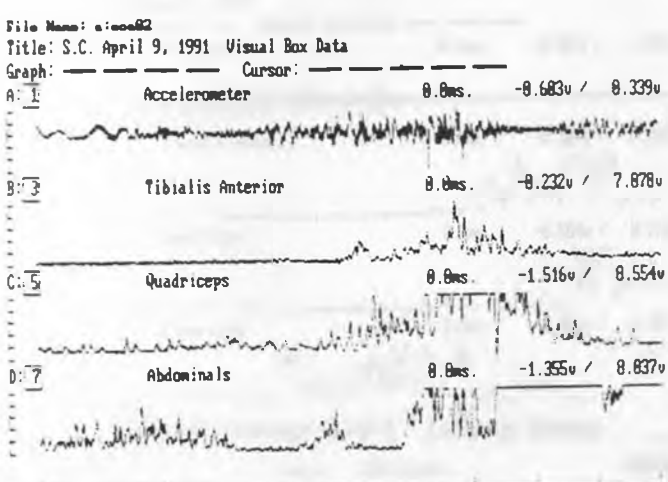
Muscle strategy: TE-G-H Latency: 340ms



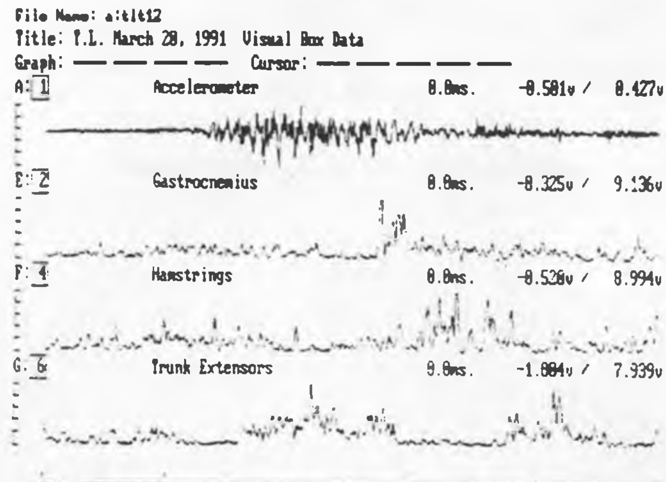
Muscle strategy: T-Q-A Latency: 500ms



Muscle strategy: H-TE-G Latency: 600ms



Muscle strategy: A-Q-T Latency: 513ms

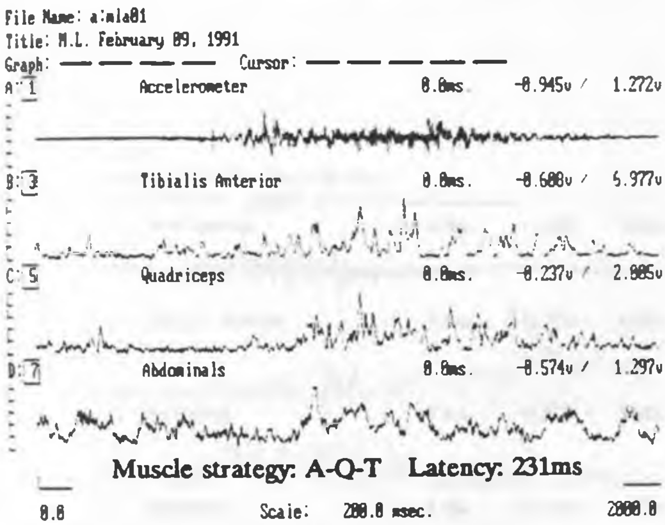


Muscle strategy: TE-G-H Latency: 85ms

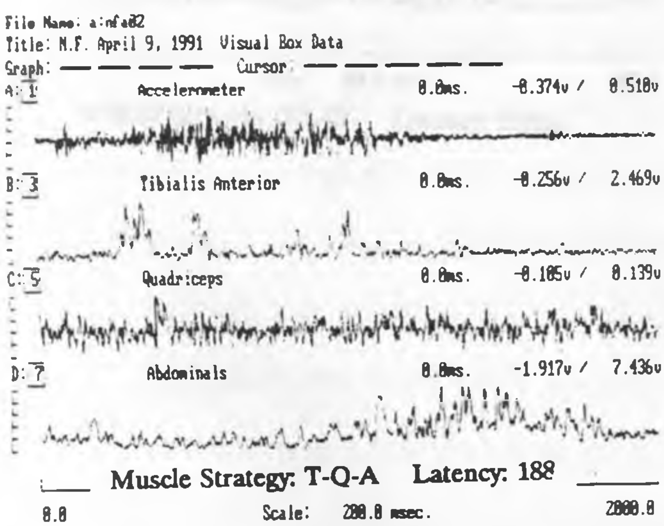
SELECTED ELECTROMYOGRAM RECORDINGS FOR INDIVIDUAL TRIALS DEPICTING MUSCULAR SYNERGIES AND ONSET LATENCIES

EXPERIENCED WALKERS AGE 2-4yrs

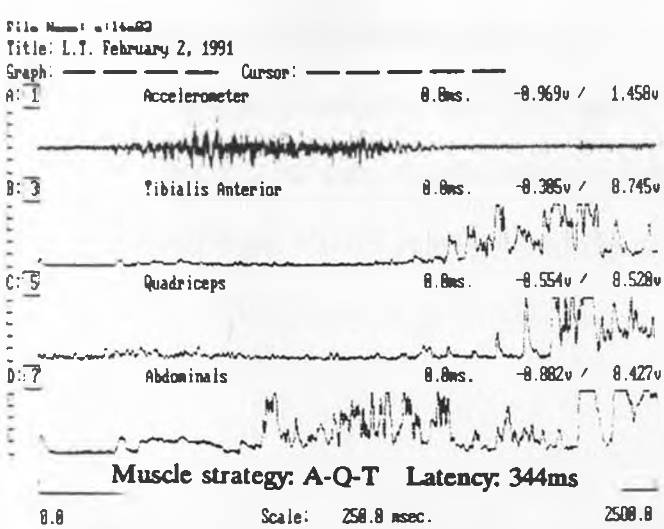
AWAY TRIALS



Muscle strategy: A-Q-T Latency: 231ms

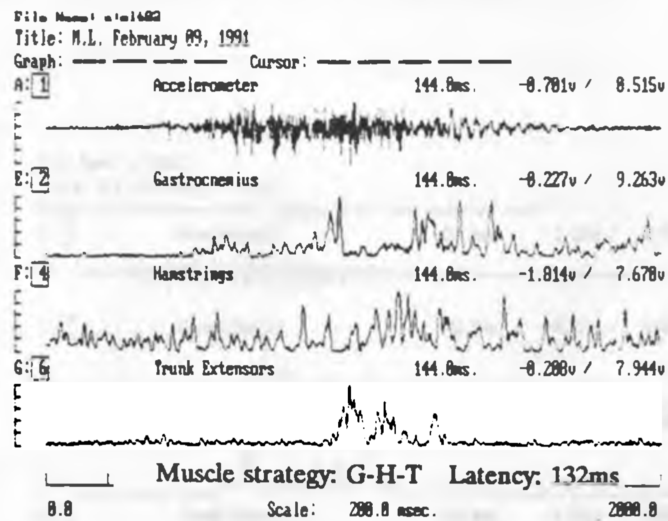


Muscle Strategy: T-Q-A Latency: 188

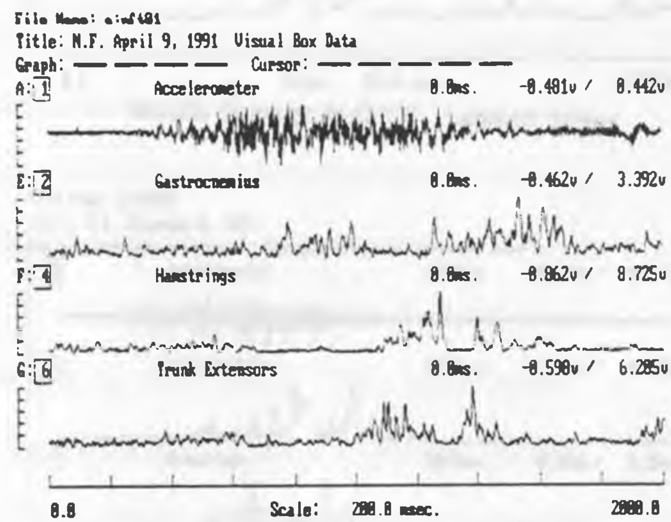


Muscle strategy: A-Q-T Latency: 344ms

TOWARD TRIALS



Muscle strategy: G-H-T Latency: 132ms

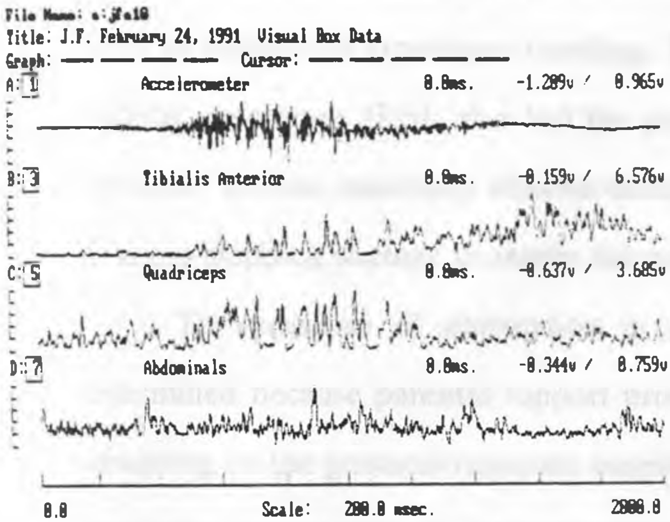


Muscle Strategy: G-TE-H Latency: 387ms

SELECTED ELECTROMYOGRAM RECORDINGS FOR INDIVIDUAL TRIALS DEPICTING MUSCULAR SYNERGIES AND ONSET LATENCIES

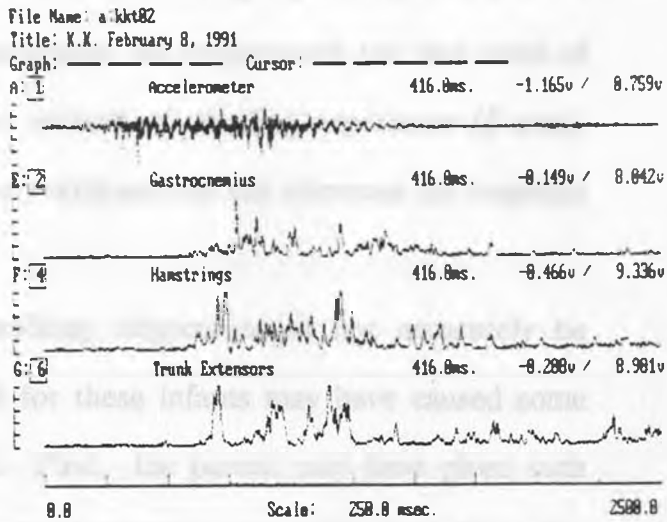
EXPERIENCED WALKERS
AGE 4-6yrs

AWAY TRIALS

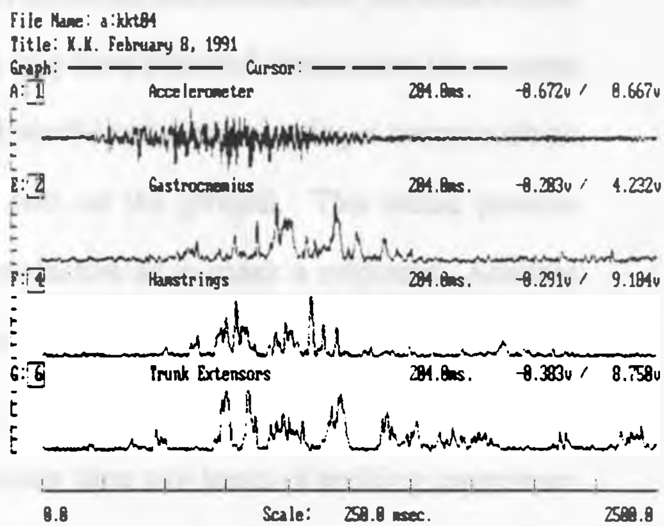


Muscle Strategy: TA-Q Latency: 100ms

TOWARD TRIALS



Muscle Strategy: H-G-TE Latency: 325ms



Muscle Strategy: G-H-TE Latency: 250ms

Secondly, it is evident that increased walking experience is clearly linked with the ability to decrease the magnitude of response. In addition, the ability to attenuate or use a stepping strategy does not appear immediately after the onset of independent walking. Rather, these capabilities emerged after four weeks of walking experience and did not seem to depend on experience crawling. For example, the subject with just one week of walking experience (EB), also had the greatest amount of crawling experience (5 mos). However, EB was maximally effected during every trial and did not attenuate the response or use a stepping strategy to regain balance.

The presence of attenuation in pre-walking subjects could not accurately be determined because parental support provided for these infants may have caused some obscuring of the postural response magnitude. First, the parent may have given such restrictive support that the interpretation of postural responses was minimized. Secondly, the parent may have varied the amount of support given to the infant after the trials began. If the parent increased support, the video coding may have depicted attenuation in response when actually none existed. In future studies, I would recommend using a harness which lightly suspends the infant while keeping their feet on the ground. This would provide support to prevent a fall, but would not be so restrictive as to mask a response. Another solution may be to train another research assistant to support the infant, in a non-restrictive but protective and constant fashion.

Thirdly, I predicted that children with greater than two years of walking experience would respond similarly to the adults. Clearly, the refinement of proprioceptive skills is continuing even after 5 years of walking experience. Furthermore, the increased variability encountered in this age group may indicate, as Shumway-Cook and Woollacott found, that they are going through a new transition phase in integrating sensory information. In addition, the variability may reflect the acquisition of a greater repertoire of strategies to address the conflict between visual and mechanical proprioceptive cues.

The second dimension of my hypothesis predicted that the presence of an ascending synergy of muscle responses would be consistent in experience walkers and that the onset latencies would decrease. This appears to be confirmed in the Toward trials of my experiment with greater variability encountered in the Away trials. The evidence may be more apparent in the Toward trials because the stimulus is more compelling when the box moves toward the subject. One limitation of the study in this respect is the possible enhancement of response due to a "looming" effect, in which the child may back away from something (e.g. the moving room) which they perceive to be on a collision course with them. The increased magnitude and frequency of response that occurred in the Toward trials across age groups, may thus be due to the additive effect of visual flow and looming effect. Future studies may desire to use a longer room to minimize the possibility of a looming effect.

Contrary to Nashner's study using platform perturbations, the activation of the response occurs much laters when using the visual room. Also, the presence of early abdominal activations during selected Away trials suggests that the use of a hip strategy in the forward direction is one of the ways the experienced walkers respond (See EMG trace for LT). In other cases, the thigh muscle was activatedfirst rather than the most distal muscle. This evidence, along with the greater onset latencies that accompany visually induced postural sway suggest that there is variance in the two mechanisms which are responsible for mechanical and visual proprioception.

SIGNIFICANCE

I hope that this study will serve to fill gaps in previous research concerning visually induced postural sway. The information I have obtained may shed light on our current understanding of the development of postural control and provide information which will aid the physician or physical therapist in diagnosing and treating children who have difficulty learning to stand and walk. For example, children afflicted diseases such as cerebral palsy and Down's syndrome often have severe motor impairments which delay the development of locomotion. If these children lack the ability to visually control posture, further development may be delayed. Future research studying the responses of children with diseases affecting postural control may contribute to a better understanding of the causes of delayed locomotion.

B I B L I O G R A P H Y

Assaiante, C., and B. Amblard (1989) 'Head-trunk coordination and locomotor equilibrium in 3 to 8 year old children.' In *The Head-Neck Sensory-Motor System. Vol 1: Evolution, Biomechanics and Basic Aspects.* (Eds. A. Berthoz, W. Graf, and P. Vidal) John Wiley and sons, Chichester.

Assaiante, C., B. Amblard, and A. Barblanc (1988) 'Peripheral vision and dynamic equilibrium control in five to twelve year old children', in *Posture and Gait: Development, adaptation, and modulation.* (Eds. B. Amblard, A. Berthoz, and F. Clarac), pp.75-83, Elsevier, Amsterdam, New York, Oxford.

Bai, D.L., B. Bertenthal, and M. Sussman (1987) 'Children's sensitivity to optic flow information for the control of stance.' University of Virginia, Charlottesville, VA.

Bertenthal, B.I., J. Campos, and C. Barret (1984) 'Self-produced locomotion: an organizer of emotional, cognitive, and social development in infancy.' In *Discontinuities in Development*, pp. 175-210. (Eds. R. Emde and R. Harmon) Plenum Publishing Corporation.

Butterworth, G., and D. Cichetti (1978) 'Visual proprioception and postural stability in infancy. A developmental Study.' *Perception*, 6:255-262.

Butterworth, G., and L. Hicks (1977). ' Visual proprioception and postural stability in infancy: A developmental study.' *Perception*, 6, 255-262.

Development of Posture and Gait Across the Life Span, edited by M.H. Woollacott and A. Shumway-Cook. University of South Carolina Press, Columbia, 1989.

Forssberg, H., and L.M. Nashner (1973) 'The Autonomy of visual kinaesthesis.' *Perception*, 2:287-294.

Fraiberg S. (1977) *Insights from the Blind*, New York: Basic Books.

Jouen, F. (1988) 'Visual-proprioceptive control of Posture in newborn infants.' In *Posture and Gait: Development, Adaptation, and Modulation.* (Eds. B. Amblard, A. Berthoz, and F. Clarac) Elsevier Science Publishers.

Jouen, F. (1984) 'Visual-Vestibular Interactions in Infancy.' *Infant Behavior and Development.* 7:135-145.

Lee, D.N., and E. Aronson (1974). 'Visual proprioceptive control of standing in human infants.' *Perception & Psychophysics*, 15, 529-32.

Lishman, J.R. and D. N. Lee (1973) 'The Autonomy of Visual Kinaesthesis.' *Perception*, 2:287-294.

Owen, B.M. and D.N. Lee (1986) 'Establishing a frame of reference for action.' *Motor Development in Children: Aspects of Coordination and Control* (Eds. M.G. Wade and H.T.A. Whiting.)

Shumway-Cook A, Woollacott M (1985) *Journal of Motor Behavior* 17:131-147.

Stroffregen, T., M. Schmuckler, and E. Gibson (1987) 'Use of Central and Peripheral optical Flow in Stance and Locomotion in Young Walkers.' *Perception*, 15:113-119.

Von Hofsten, C. (1979) 'Development of Visually Directed Reaching: The Approach Phase.' *Journal of Human Movement Studies*, 5: 160-178.

Woollacott, M.H. (1988) 'Posture and Gait from Newborn to Elderly.' In *Posture and Gait: Development, Adaptation, and Modulation.* (Eds: B. Amblard, A. Berthoz, and F. Clarac).