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Not just standing there: The use of postural coordination to aid visual tasks

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Abstract

Postural control is an integral part of all physical behavior. Recent research has indicated that postural control functions in a manner that facilitates other higher order (suprapostural) tasks. These studies, while showing that postural sway is modulated in a task specific manner, have not examined the form of postural coordination that allows for the achievement of these higher behavioral goals. The current study examined the relation between visual task constraints (viewing distance), environmental constraints (changes in the surface of support), and the postural coordination employed to complete the task. Thirty-one participants were asked to perform a reading task while standing on various surfaces. Postural motion was recorded from the head, cervico-thoracic spine, sacrum (hip), and ankle. It was found that body segment coordination changed as a function of surface characteristics and task constraints. Additionally, the overall pattern of postural sway (head motion) replicated that which was found by Stoffregen et al. [J. Exp. Psychol. Human Percep. Perform. 25 (6) (1999) 1641]. These findings suggest that postural adaptation involves more than basic reduction or increase of motion; it involves the functional coordination of body segments to achieve a particular goal. The data further suggest that there is a need to examine postural control in the absence of external perturbations.

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1. Introduction

Postural control and coordination often is taken for granted as it is something that we do quite successfully under most circumstances (indeed, we often only think about postural control when there is a risk of losing it). Upon closer inspection, we find that maintaining posture only appears easy. Bipedalism (upright stance) has many advantages (e.g., tool use), but its main disadvantage is that it is unstable and must be under constant control.

Understanding how this control is maintained is important as "[B]ehavior depends on posture and is inseparable from it" (Gibson, 1974). Reed (1982) in a similar vein asserted that the control and coordination of posture is one of the basic action systems. Reed (1982) suggested that all behaviors could be viewed as collections of postures and movements that are enacted to exploit available resources. In short, the suggestion is that posture should not be thought of as an independent system, nor is it maintained for its own sake; rather posture is maintained in order to facilitate other actions (Riccio & Stoffregen, 1991; often referred to as *suprapostural* goals, see Stoffregen, Smart, Bardy, & Pagulayan, 1999). To emphasize this characterization of posture, Smart and Smith (2001, p. 342) proposed that posture be defined as a "behavior whose purpose is to facilitate other behaviors through the maintenance of a given coordination of segments that are biomechanically viable (i.e. goal is achieved without loss of balance) and efficient (energy expenditure is minimized)." This characterization of posture suggests that researchers should determine how this facilitation is achieved and maintained.

Stoffregen et al. (1999) performed a study that demonstrated that posture is modulated to support suprapostural behaviors. They modified a paradigm that Lee and Lishman (1975) used to demonstrate the importance of vision for postural control. Participants stood in a large lecture hall, and their spontaneous (unperturbed) sway was measured as they fixated objects at different distances. When they looked at a distant wall, their anterior–posterior (AP) sway amplitude was large. When an object was placed directly in front of them, sway amplitude decreased. This finding has been replicated several times in a variety of experiments using unperturbed sway (Dijkstra, Gielen, & Melis, 1992). In the Stoffregen et al. (1999) study, a third condition was added, as an extension to the original methodology in which the near-target was left in place, and the participant was told to ignore it, and fixate on the far-target. The influence of looking distance on unperturbed postural motion in a number of different situations was examined. They found that when participants looked past the near target, their sway was the same as when it was not there. Thus, it was concluded that posture is adaptive and task-specific, rather than automatic and visually controlled as posited by Lee and Lishman (1975). In an additional study performed by Stoffregen, Pagulayan, Bardy, and Hettinger (2000), it was found that varying the constraints of the target (staring at a blank target versus having text on the target that the participants had to read) resulted in task specific modulation of postural sway. Postural motion was reduced when performing the reading task relative to staring at the blank target again supporting the notion that posture is functionally regulated by the constraints of the task. Riley, Baker, and Schmit (2003) demonstrated that postural motion is influenced by cognitive tasks as well. They found that postural sway was minimized when the cognitive task increased in difficulty.

Other studies have demonstrated that postural motion can be influenced by altering the biomechanical properties of the person, the physical properties of the surface of support, or the constraints of the suprapostural task (Bardy, Marin, Stoffregen, & Bootsma, 1999, 2002; Marin, Bardy, & Bootsma, 1999; Oullier, Bardy, Stoffregen, & Bootsma, 2002). Each study demonstrated that postural motion was modified adaptively to facilitate performance of the suprapostural task. People tended to adopt an ankle (in-phase ≈20°; where ankle flexion/extension is the primary mechanism for making postural adjustments) or hip (out of phase ≈180°; where hip flexion/extension is the primary mechanism for making postural adjustments) strategy when presented with a dynamic task (responding to a visual perturbation). The postural behavior exhibited in these studies can be described as *compensatory*. Compensatory behaviors are characterized by actions that attempt to bring the body back into equilibrium if it has been compromised. These actions are often achieved through conscious, gross motor control (e.g. stepping), and are usually in response to some externally imposed motion of the support surface or motion of the visual field (Roberts, 1995; see for example Lee & Lishman, 1975; Nashner & McCollum, 1985). Much of the literature in postural control employs some form of perturbation, which has provided information regarding how balance is regained after it is disturbed (see Stoffregen et al., 1999 for a discussion of this). Hence, there is a good understanding of how the postural system recovers from disruptions. However, there is evidence for another class of postural behaviors that are employed in the absence of external perturbations termed *maintenance* actions. These are actions that serve to maintain equilibrium under normal conditions, i.e., not involving crossing of the stability borders (for a discussion of these borders see Riccio & Stoffregen, 1988; Smart & Smith, 2001). These actions are usually "automatic" in that they do not require conscious intent. There are very few studies concerning this type of control, as many researchers treat sway in non-perturbed settings as noise, and often suggest that the goal of posture under these situations is to minimize sway (e.g., Dijkstra et al., 1992 propose a sway-minimization hypothesis). The absence of studies concerning maintenance actions seems to be a result of an implicit assumption among researchers that compensatory and maintenance actions are equivalent behaviors. However, recent data suggest that compensatory and maintenance responses may generate different coordination patterns (Smith, Otten, & Smart, 2002, 2003). Other studies that have examined postural control under non-perturbed (but unusual) conditions have also shown that postural motion is influenced by changes in surface of support and availability of visual information, but have tended to consider the individual contributions of different joints rather than their coordination (see for instance Blackburn, Riemann, Myers, & Lephart, 2003; Riemann, Myers, & Lephart, 2003).

Thus there is a wealth of information regarding the compensatory nature of posture and an emerging literature that is revealing the functional nature of postural control. However, there is little information available concerning how a given posture is maintained in order to achieve a particular goal in the absence of a perturbation. In the present study we sought to examine how postural coordination is modified as a function of changes in surface characteristics and task constraints. We had participants stand on various surfaces while performing a visual task (letter counting). We varied the constraints of the visual task by changing the distance of target (in the same manner as Stoffregen et al., 1999). While participants were performing the task, we recorded the participants' postural motion in order to measure the influence of task and surface on coordination. Based on the work of Stoffregen et al. (1999, 2000) and Riley et al. (2003) we predict that gross changes in the magnitude of postural sway will reflect changes in the suprapostural task. Based on principles espoused by Nashner and McCollum (1985) and the work of Bardy et al. (1999), we expect that the changes in the coordination of body segments will reflect changes in the characteristics of the support surface.

2. Method

2.1. Participants

Thirty-one (16 female, 15 male) undergraduate students from Miami University participated in this study and received course credit for participating. The participants' average age was 21 yrs. The participants had an average height of 1.73 m and weight of 65.91 kg. All participants were in good health and had normal or corrected to normal vision with no history of falls, dizziness, or inner ear/vestibular dysfunction. Participants were randomly assigned to one of four surface conditions. Participants were aware of the fact that we were measuring their postural motion, but not the particular aims of the study. Participants were asked to wear comfortable clothes and gym shoes to the testing session. Participants were treated in accordance with American Psychological Association (APA) ethical standards at all times (APA, 1992).

2.2. Materials

2.2.1. Stimuli

A short reading passage served as the visual target. The passage was an ice cream recipe that contained 15 lines of text (the last line only contained one word). The passage contained 57 "O"s and 95 "E"s that the participants had to count during each trial (one letter per trial). These letters were chosen to ensure that the participants would be engaged in the task for the duration of the trial. The letters were also similarly shaped and appeared with equivalent frequency (with the exception of four

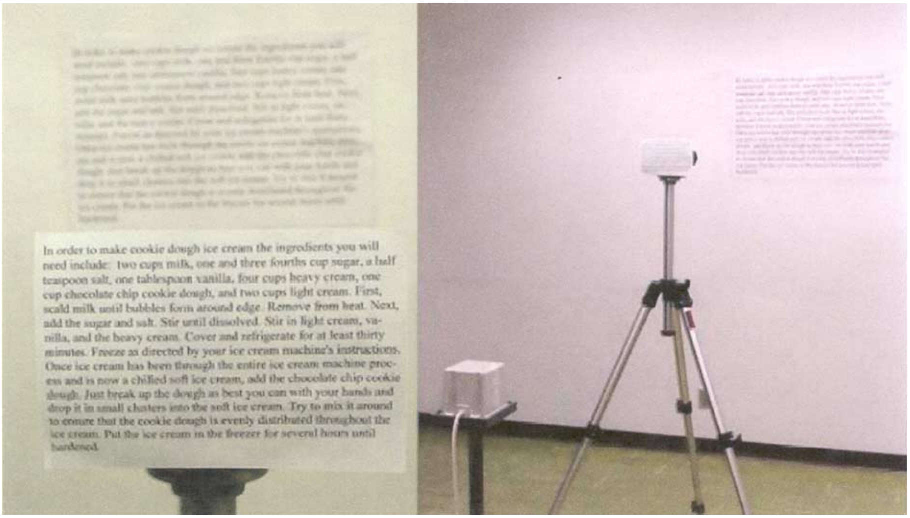

Fig. 1. Stimuli setup for current study (see text for explanation).

lines where the ratio of "E"s to "O"s was 3:1). Two targets were employed: The first target was attached to a tripod 0.4 m from the participant and was 10.16 cm × 15.24 cm (12° vertical × 20° horizontal visual angle). The second target was placed on the laboratory wall 3 m from the participant and approximately 1.5 m from the laboratory floor. To achieve the same visual angle as the near target, the dimensions of the wall target were 32 cm × 55 cm; font sizes for the near and far target were scaled to have the same visual angle (2.92° × 2.92°; see Fig. 1).

2.2.2. Surfaces

Four surfaces were employed, a wide plank (61 cm × 61 cm), a narrow beam (8 cm × 122 cm), a foam–rubber mattress (61 cm × 61 cm, 2.5 cm thick), and a foam beam (biofoam roller; 8 cm × 91 cm). All surfaces were raised 8 cm from the laboratory floor.

2.2.3. Motion tracker

Postural motion was recorded using a magnetic tracking system (Flock of Birds; Ascension, Inc.: Burlington, VT). This system detects motion in six degrees of freedom (3 axes of translation and 3 of rotation). A centrally located emitter creates a low-intensity magnetic field of known strength, extent and orientation. Receivers (birds) move within this field. The system can detect the position of each bird to an accuracy of 1 mm. Data from the birds were sampled at a rate of 20 Hz and stored on computer for later analysis. Four "birds" were employed, one on the head, one on the vertebra prominens (C7), one on the base of the spine (S1: sacrum), and the final bird on the (right) ankle (lateral malleolus). The ankle and head "birds" were attached using Velcro to flexible head/wrist bands. The upper-spine "bird" was attached using a piece of athletic tape that was also crossed around the trunk and chest for secure placement. The hip "bird" was attached using a flexible waistband made of Velcro.

2.3. Procedure

At the start of the testing, the experimenter introduced herself and provided a brief overview of the experiment in order to obtain informed consent. The participant was then given a brief balance test in which the participant had to stand on one leg with her or his eyes closed for 30 s. This was done to establish that every participant met minimal balance standards. If a participant could not perform the task, s/he was allowed to leave with credit for the study. All participants were able to pass this balance check. Participants were then outfitted with the motion sensors and the task was explained to them. Participants were told that they would be standing on one of four surfaces and that they would have to maintain balance on the surface on which they were standing. The participants were then informed that they would be simultaneously performing a reading task that entailed counting the number of "O"s or "E"s in a short passage. The reading task was used to insure that the participants were focusing on the appropriate target, but was not the main interest of the experimenters. This passage would either be placed right in front of them or on the far wall. In either case the task was the same and the experimenter would inform them of which target to fixate. The participants completed twelve 60 s trials (4 focusing on the near target – *object_near*, 4 focusing on the far target with the near target absent – *No Object*, and 4 focusing on the far target with the near target present – *object_far*). For each trial the participant counted the number of "O"s and "E"s silently, if the participant reached the end of the passage before the end of the trial s/he was told to alert the experimenter and start at the top again. Target order and letter assignment were counterbalanced across participants. At the end of each trial the participant indicated how many letters were counted and where in the passage s/he was. Participants were allowed to rest in between trials if needed. Performance data from each trial was recorded and stored for later analysis. Postural data was stored on a computer for later analysis.

3. Results

For each participant, performance data was collected for the visual task. The number of letters that the participant reported were compared to the actual number of letters (based on the participants' stopping point) and converted to a percentage. These percentages were compared across target and surface. Postural motion data was collected from the head, upper spine, sacrum (hip), and ankle. For the current analysis we examined motion in the AP, lateral, and pitch (rotation about the lateral axis) axes. We performed separate 3×4 mixed ANOVAs (distance $\times$ surface) on the variability of head motion in the AP and lateral axes. We also calculated a ratio between the amount of pitch rotation in the hip and ankle to serve as an index of the type of coordination employed to facilitate the task. These ratios were also analyzed using a 3×4 ANOVA.

3.1. Performance data

3.1.1. Accuracy

Overall participants did quite well, but were significantly more accurate when counting "O"s (91%) than when counting "E"s (84%); $F_{(1,60)} = 23.37$, $p < 0.05$. Generally participants were just as accurate when standing on the beam surfaces (87%) as when on the flat surfaces (88%). There was a significant surface by viewing distance interaction; $F_{(6,120)} = 2.73$, $p < 0.05$. This interaction was the result of lower accuracy in the object_far condition for the hard surface (81%) compared to the other surfaces (mean = 89%) for the same distance condition. In the no object condition there was a slight downward trend in accuracy across surfaces. In the object_near condition accuracy was slightly better on the foam surfaces than the hard surfaces.

3.1.2. Passage completion

Participants in this study did not significantly differ in the amount of text read. Surface of support, viewing distance, and letter choice yielded similar completion rates. Overall participants were able to read 80% (12/15 lines) of the passage on average. We did observe a slight downtrend trend across surfaces as participants completed 87% (13/15 lines) of the passage when standing on the hard surface and 73% (11/15 lines) of the passage when standing on the foam beam.

3.2. Postural data: Head motion

3.2.1. AP motion

There was a significant main effect of viewing distance (across surfaces) on AP variability, $F_{(2,54)} = 81.95$, $p < 0.05$. Sway in the object_near condition ($M = 0.47$ cm, SE = 0.03 cm) was significantly lower than in the no object ($M = 0.79$ cm, SE = 0.04 cm) and object_far ($M = 0.64$ cm, SE = 0.04 cm) conditions. Sway in the object_far condition was also significantly lower than sway in the no object condition. Surface of support did not significantly influence AP variability (there was a slight upward trend with the hard surface having the least amount of variability ($M = 0.55$ cm, SE = 0.07 cm) and the foam beam exhibiting the greatest amount of variability ($M = 0.71$ cm, SE = 0.07 cm)).

Pairwise comparisons among distance conditions were then performed for each surface individually. In the hard surface condition, AP variability was significantly lower for the object_near condition than in the object_far and no object conditions (which did not differ from each other). In the remaining three surface conditions, AP variability was highest in the no object condition, and lowest in the object_near condition with the object_far condition falling in the middle. See Fig. 2A for a depiction of these results.

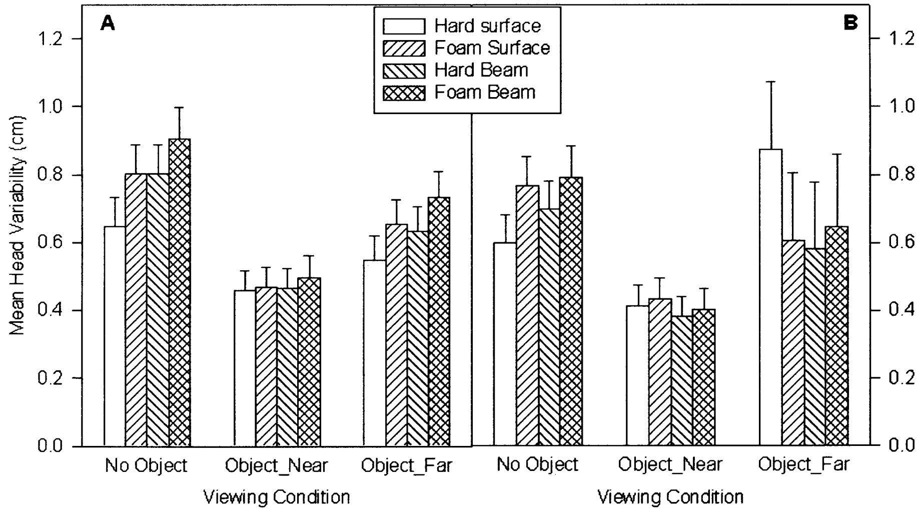

Fig. 2. Mean (SE) head variability as a function of surface and viewing condition: (A) A–P variability; (B) M–L variability ($N = 31$).

3.2.2. Lateral motion

There was a significant main effect of viewing distance (across surfaces) on lateral variability, $F_{(2,54)} = 8.83$, $p < 0.05$. Sway in the object_near condition ($M = 0.41$ cm, SE = 0.03 cm) was significantly lower than in the no object ($M = 0.72$ cm, SE = 0.04 cm) and object_far ($M = 0.68$ cm, SE = 0.10 cm) conditions. Sway in the object_far condition was also significantly lower than sway in the no object condition. Surface of support did not significantly influence lateral variability (there was a slight downward trend with the hard surface having the most amount of variability ($M = 0.63$ cm) and the hard beam exhibiting the least amount of variability ($M = 0.55$ cm)).

Pairwise comparisons among distance conditions were then performed for each surface individually. In the hard surface condition, lateral variability was significantly lower for the object_near condition than in the object_far and no object conditions (which did not differ from each other). In the remaining three surface conditions, lateral variability was significantly higher in the no object condition than in the object_near condition. The object_far condition did not differ significantly from either of the other two distance conditions. See Fig. 2B for a depiction of these results.

3.3. Postural motion: Hip–ankle coordination

As stated above, a ratio was generated by dividing the variability of hip rotation by the variability of ankle rotation in the pitch axis. A ratio of 1 indicates equivalent amounts of hip and ankle rotation. Ratios less than 1 indicate more ankle rotation (ankle strategy), while ratios greater than 1 indicate more hip rotation (hip strategy). There was a significant effect of surface, $F_{(3,120)} = 4.22$, $p < 0.05$. Participants used

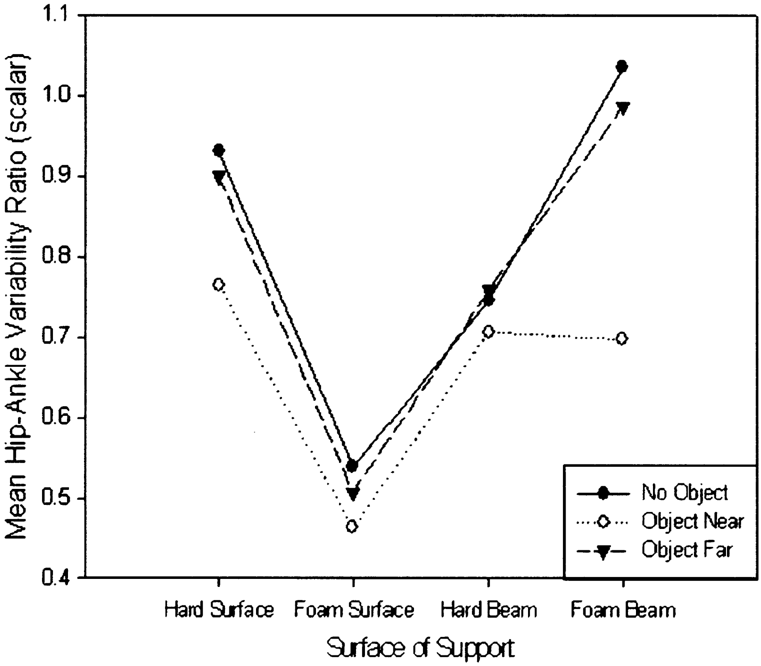

Fig. 3. Mean hip–ankle variability ratios as a function of surface and viewing condition ($N = 31$).

more ankle on the foam surface than on the other surfaces. There was also a marginal effect of distance on hip–ankle coordination, $F_{(2,240)} = 2.87$, $p = 0.058$. Participants relied more on ankle motion in the object_near condition (mean = 0.66, SE = 0.04) across surface conditions. The no object (mean = 0.81, SE = 0.06) and object_far (mean = 0.79, SE = 0.08) conditions did not differ from one another. See Fig. 3 for a depiction of these results.

4. Discussion

In this study we sought to examine the influence of task and environmental constraints on postural coordination in unperturbed stance. As found in Stoffregen et al. (1999, 2000), the analysis revealed that overall postural sway (represented by head movement) was influenced by the constraints of the suprapostural task. Postural sway in the object_near condition was reduced relative to the other viewing conditions. In fact, head variability for the object_near condition (≈0.4 cm) was nearly identical across surfaces despite the slight upward trend across surfaces found when averaging across the viewing conditions. The overall effect of surface on postural (head) sway was not significant indicating that as predicted postural movement was primarily constrained by the needs of the suprapostural task. However, while support surface characteristics did not impact head motion, it did influence the kind of coordination employed by the participants.

We observed that hip–ankle coordination changed as a function of the surface characteristics. Participants tended to employ nearly equivalent hip and ankle rotations when on the hard surface and foam beam, relative to the foam surface (where there was considerably more ankle rotation) and hard beam. While it is not surprising that coordination changed as a function of the surface characteristics, it is the form of those changes that are interesting to note. Overall, participants preferred to use more of an ankle strategy even when this mode of operation would not nominally be supported by the surface. This finding is contrary to the findings of Bardy et al. (1999, 2002) and Nashner and McCollum's (1985) compensatory or perturbation-based postural model. The different outcome of the present current study supports the hypothesis that maintenance and compensatory behaviors are in fact, not identical. In other words, the patterns of joint coordination adopted during natural stance situations seem to differ from those produced in reactionary situations. It is important to note that the measure employed in the study is spatial rather than temporal, in other words the measure tells us the relative amount of movement among joints, but not when these joint movements are occurring.

Further, we observed that the type of coordination employed differed as a function of the constraints of the suprapostural task. In the conditions where the participant was required to focus on the far target (no object, object_far), the pattern of hip–ankle coordination was identical across surfaces whether or not the near target was present. When the participants were told to focus on the near target (object_near), the pattern of coordination across surfaces differed. In the object_near condition, participants primarily relied on an ankle strategy on each surface, in principle, because of the need for finer resolution of movement in order to facilitate viewing the text on the near target (hip movements tend to be large and to displace the center of mass). In other words, participants seemed to handle the difficulty of focusing on a small target while standing on increasingly difficult surfaces by adopting a rigid-segment strategy, in which they primarily allowed the ankle to produce the necessary control. In the far target conditions, we observed that both the hip and ankle were being utilized, indicating perhaps the perception of the availability of other modes of action that would support looking at the far target, but not the near target. This increased flexibility in coordination may reflect the decreased demands of the suprapostural task (reading) afforded by the reduced optical flow produced by postural movements when looking at the far target.

Although the overall pattern of postural (head) sway is similar across surfaces, inter-joint coordination modes were vastly different. It appears that to accomplish the suprapostural task, different segment coordination patterns were engaged to satisfy the specific constraints imposed by the surface and task. When more precision was needed/warranted by the task (such as in the object_near conditions) we see an adoption of a rigid-segment strategy (evidenced by the lower hip–ankle ratios). When the task was less demanding, we saw an increased flexibility in segment movements (as suggested by the relatively higher hip–ankle ratios). The implication of these findings is that models of postural control should be explicitly multi-segmental and should account for not only biomechanical factors, but cognitive or task relevant factors as well. In terms of measurement and data collection, these findings suggest that studies which employ a single measurement point (such as center of pressure (COP) or mass (COM)) may not allow for a complete understanding of how postural coordination influences not only stance, but the ability to successfully engage in other "higher order" tasks.

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