ISSUES IN THE DEVELOPMENT OF POSTURAL CONTROL

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The past few years have seen a marked growth of interest in motor control. This increased interest has lead to the accumulation of a wealth of data, specifically work investigating postural control and its development. This work, reviewed in the preceding papers by Francois Jouen and Marjorie Woollacott, has elucidated a number of interesting issues, and has highlighted a variety of general processes in development. The purpose of this discussion is to underscore some of the important issues and questions that researchers have examined, and which are discussed by Woollacott and Jouen. Additionally, the intention is to highlight some concerns and problems requiring further research and thought.

Although postural control has traditionally been thought solely dependent upon proprioceptive and vestibular processes, recent research has demonstrated that visual information plays a similarly crucial role in maintaining balance. The classic work of David Lee (i.e. Lee & Aronson, 1974) demonstrated that transformations of the optic array simulating a loss of balance by observers induced postural compensation in these subjects. This result has been observed across a wide range of ages, from 5-month-old infants (Bertenthal & Bai, in press), to newly standing children (Lee & Aronson, 1974; Stoffregen, Schmuckler, & Gibson, 1987), to adults (Andersen & Braunstein, 1985; Lee & Lishman, 1975; Lishman & Lee, 1973; Stoffregen, 1985, 1986). In addition, the result has been observed for a variety of different postures, including sitting (Bertenthal & Bai, in press; Butterworth & Hicks, 1977), standing (Lee & Lishman, 1975, Stoffregen, 1985, 1986) and walking (Schmuckler & Gibson, 1989; Stoffregen et al., 1987).

I. ON INTEGRATION.

Given the wide array of available information relevant to postural control, one of the primary issues researchers have addressed concerns the process of integrating three different information sources -proprioceptive, vestibular, and visual. As such, in the preceding papers Woollacott and Jouen address the problem of integration, as well as examine the

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development of this process. The very breadth of topics discussed in these articles supports the general idea that integration of input is essential for appropriate balance control, and that integration occurs on a variety of levels. At one extreme, integration can be found at the neural level: Jouen notes the convergence of various sensory inputs implicated in postural control at a single location within the nervous system, the central vestibular neurons. According to Jouen, this convergence is one means of integrating information from different inputs, and has dramatic implications as to the nature of the information conveyed by the different sensory systems. This convergence suggests a common coding dimension across all three inputs, thereby constraining the nature of the information (specifically, information concerning the direction and velocity of motion) available to the postural control system.

A similar theme of integration is addressed in some of the work reviewed by Woollacott, which includes research examining inter-sensory integration of visual, proprioceptive and vestibular input at the level of postural responses of children varying in age (Shumway-Cooke & Woollacott, 1985). Finally, although not explicitly discussed by Jouen or Woollacott, integration can occur on a functional level. There are a variety of types of integration at this level. For example, coordinated movement requires integration of different functions in complicated motor tasks like reaching, in which balance must be maintained throughout a series of different postures, while grasping occurs (cf. von Hofsten, 1982). Another example is locomotion through a crowded environment, which necessitates integrating postural control with movement around obstacles and through openings. Other cognitive tasks, such as planning a route, could be added to this growing list of situations requiring integration.

II. DIFFERENTIATION OF INFORMATION.

While the importance of processes such as integration is clear in the work discussed by Woollacott and Jouen, other important processes also exist. Specifically, concurrent with the integration of the differing inputs implicated in postural control, there exists the complementary process of differentiation of information. Differentiation has long been considered a crucial factor in perceptual learning and development (Gibson, 1969; Gibson & Gibson, 1955), and has recently been implicated as playing an important role in motor coordination and postural control (Stoffregen et al., 1987; Schmuckler & Gibson, 1989). An example of this process can be observed in the selective use of optical flow for controlling posture. Research by Stoffregen demonstrated that adults responded differentially to optical information varying in its geometrical structure. Stoffregen et al. (1987) and Bertenthal and Bai (in press) observed similar findings using newly standing children. Schmuckler and Gibson (1989) extended these results, and suggested that different types of optical flow structure subserved varying functions in postural control and locomotion. Additionally, a developmental trend was observed, with differentiation of optical flow information being incomplete in younger children.

Along with this differentiation of information within a single sensory input, differentiation occurs between modalities. In the classic moving room situation (Lee & Aronson, 1974) visual information suggests a loss of balance while proprioceptive and vestibular inputs suggest postural stability, thereby creating a conflict. To resolve this conflict, information for postural instability must be differentiated from information specifying postural stability. The work reviewed by Woollacott (Shumway-Cooke & Woollacott, 1985) has provided elegant empirical manipulations of this type of conflict situation. A final example concerns differentiation of information subserving multiple functions within a single information source. For example, when observers receive imposed optical flow while walking -- such as that which occurs within a moving room -the optical flow produced by self-motion must be distinguished from the optical flow superimposed by the externally moving texture. In general, differentiation is as pervasive a process as integration, and is also evident on a variety of levels of analysis. We must endeavour to understand each of these processes, and, indeed, to understand their interplay. A second topic discussed in the preceding papers involves the sensitivities and limitations of the postural control system. One approach to studying this area examines the nature of the information that induces postural compensation. Examples of this approach have already been discussed, and include the work on measuring the relative effectiveness of optical information that differs in its geometric structure in inducing postural compensation (Bertenthal & Bai, in press; Stoffregen, 1984, 1985; Stoffregen et al., 1987). Other researchers have begun to test sensitivity to optical information for postural control in even younger subjects. Along these lines, Jouen presents some intriguing evidence for rudimentary sensitivity in 3-day-old neonates to visual input specifying postural perturbations. Here, young infants responded to a sequentially activated series of lights (intended to simulate forward or backward movement) with corresponding changes in head pressure, which were interpreted as postural reactions. However, two different patterns of responses occurred -- "consistent" and "opposite" postural reactions. Consistent responses represented directionally appropriate postural compensation, while opposite responses implied inappropriate head movements. Although this work is moving in an interesting direction, care must be taken in interpreting these results. It is unclear in what sense opposite responses should be considered as evidence for postural compensation. The primary function of postural control is maintaining equilibrium with respect to the environment; that is, to keep one's balance throughout a variety of different motor tasks and positions. The opposite (directionally inappropriate) head movements create, in effect, greater postural instability, as opposed to the consistent head movements, which produce an increase in postural equilibrium. It is possible that these two patterns represent similar visual flow sensitivity, with differing responses resulting from inappropriate (or inadequate) muscular control for the "opposite" reactions. Without further evidence investigating this effect, however, it is difficult to align these results with the data gathered on young children and adults, who rarely respond in a directionally inappropriate manner.

III. DEVELOPMENTAL PROCESSES.

The final issue to be mentioned here concerns the implications for developmental processes in the data described by Woollacott and by Jouen. Based on the large number of observed age differences, a few general developmental processes are discernable. First, and most obviously, there is the general trend toward more efficient integration and differentiation over the course of development. Such changes are evidenced on the neural level, as in the results described by Jouen, as well as on the behavioral level (see Shumway-Cooke & Woollacott, 1985). Generally, this is not a surprising result -- one of the most common themes in developmental psychology is a refinement of abilities with increasing age. A second and more interesting process is the evidence concerning "recalibration" of motor skills as children age, a process particularly noticeable at developmental transition points. For example, Woollacott discusses data originally gathered by Pope (1984), in which precrawling infants, who initially responded to optical flow by moving their heads, exhibited a decrease in sensitivity to this information at the onset of crawling. One interpretation of this result is that, at such transition points in development, learning new postures necessitates the reduction of the potential degrees of freedom for these activities, so as to decrease the possible variability in these activities. Such constraints would show up as behavioral "rigidity", or a lack of sensitivity to potentially confusing information. As infants become more skilled in their new motor task, the previously constrained degrees of freedom can be released, resulting in a shift from behavioral rigidity to behavioral flexibility. Some preliminary research from my laboratory (Schmuckler, 1989), provides data consistent with this hypothesis. This work examined the effects of visual guidance of locomotion on kinematic parameters of children's gait. In these studies, novice walkers (approximately 15 months of age) walked in three environments, each requiring varying degrees of visual guidance. Changes in children's gait patterns as a result of these context differences were assessed by examining gross parameters of walking style, such as stride length and walking speed, along with the variability associated with these measures. Generally, there was little evidence of gross changes in gait cycles for any of these measures across the different conditions. Although clearly preliminary, one possible interpretation of these results is that these novice walkers are fairly rigid in walking style, showing little ability to subtly modulate their gait in response to the external environment. If true, then increased locomotor experience should bring with it greater flexibility in walking, allowing for finer adjustments in locomotor style based on the surrounding context.

The growth of interest in motor control, along with the rise in research relating to these issues makes this a dynamic and exciting field in which to be involved. While a great deal has been discovered about the processes and skills necessary for postural control, clearly there remains a wide array of possibilities for further work. Increased devotion to identifying the factors underlying motor performance, along with attention to developmental processes, promise to be interesting and rewarding endeavors.

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