Adaptation of Postural Control in Normal and Pathologic Aging: Implications for Fall Prevention Programs

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Exercise interventions aimed at reducing falls in the elderly rest on several very important assumptions. One important pair of assumptions is that falling in the elderly is related to poor control of balance and that balance can be improved by practice and exercise. Fortunately, basic studies of postural control provide at least partial support for these assumptions. Extensive studies of postural control in both humans and animals suggest that the postural control system is not a fixed system of stereotyped reflexes, but rather is a highly complex and adaptable system, capable of accommodating changes in the biomechanical characteristics of the environment, changes in task requirements, and even the effects of disease (for reviews, see Horak, 1996; Horak & Macpherson, 1996). These assumptions are further supported by several exercise interventions that have been shown to reduce the incidence of falling (Horak, Jones-Rycewicz, Black, & Shumway-Cook, 1992a; Hu & Woollacott, 1994a, 1994b; Shepard & Telian, 1995; Shumway-Cook, Gruber, Baldwin, & Liao, 1997; Snow, 1999; Wolf & Gregor, 1999; Wolter & Studenski, 1996).

Most interventions for fall prevention, however, consist of a fixed set of exercises performed by all participants, and this points to another important assumption. Interventions relying on exercise or balance training programs assume that the elderly all fall for similar reasons. However, experimental studies have shown that postural control is not a simple function; rather, it consists of many different components (Dietz, 1992; Horak, 1997; Horak, Shupert, & Mirka, 1989; Horak & Macpherson, 1996; Massion, 1992). Every voluntary movement is associated with a specific postural adjustment that anticipates the destabilizing forces generated by the movement. In addition, rapid, automatic postural responses are evoked whenever there is a perturbation to the body that causes dysequilibrium or alters postural orientation. To produce these responses, the central nervous system needs to detect the direction and magnitude of the perturbation and select

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the response needed to restore equilibrium. The response must then be executed in time to prevent a fall. The sensorineural, neuromuscular, and musculoskeletal functions involved in the detection of balance perturbations, the selection of appropriate responses, and the execution of these responses make up the components of postural control.

Because the control of balance is a complex behavior consisting of multiple components, the reasons for falling in elderly individuals may differ depending on which components of the postural control system are not working optimally. For example, some individuals may have losses of sensory function that impair the ability to detect falling and result in delayed postural response times. Other individuals may have central nervous system disorders that limit their ability to adapt their postural responses to different environmental conditions. Still others may have relatively intact neural function but lack the muscular strength to recover from a loss of balance. These results suggest that a complete assessment of a balance disorder requires the comprehensive evaluation of many components of postural control, including biomechanical components, such as strength and range of motion; sensory components, such as vestibular, visual, and somatosensory function; and motor components, such as scaling response amplitudes to perturbation magnitudes. Intervention strategies to prevent falls must take into consideration the specific postural control deficits in each individual. The fact that the most successful interventions to date have included both balance training and strength building exercises provides evidence for this approach (Horak, Jones-Rycewicz et al., 1992; Hu & Woollacott, 1994a, 1994b; Shepard & Telian, 1995; Shumway-Cook et al., 1997; Snow, 1999; Wolf & Gregor, 1999; Wolter & Studenski, 1996). Combined programs would necessarily address more different components of postural control.

In this paper, the results of basic studies of the effects of two different neural pathologies on automatic postural responses are presented, both to illustrate the different components of postural control, and to illustrate the adaptability of the postural control system. Studies of postural control in patients with loss of somatosensation in the feet due to diabetic peripheral neuropathy are presented to show the role of sensory information in postural control and examine the effects of sensory loss. Studies of postural control in patients with Parkinson's disease are presented to show one of the roles of the central nervous system in postural control and to demonstrate how the normal postural control system adapts to changes. Although the studies presented here were aimed at determining the effects of pathology on postural control, the studies have direct implications for both the assessment of balance disorders in the normal elderly population and for the development of specific fall prevention interventions.

**Pathology and the Decline of Postural Stability**

Many studies of postural control in the ostensibly normal elderly show declines in stability with age (Bates, Pruess, Souney, & Platt, 1995; Horak et al., 1989; Tinetti, Williams, & Mayewski, 1986; Vellas, Toupet, Rubenstein, Albareda, & Christen, 1992; Woollacott, Moore, & Hu, 1993). In fact, this finding is so common that it is often assumed that age alone accounts for the increase in instability (e.g., see Belal & Glorig, 1986). Many studies have documented a wide variety of deficits in many of the critical systems for postural control, including changes in sensory thresholds, slowing in central nervous system functions, and biomechanical deficits, including muscle weakness (see Horak et al., 1989, for a review). Nevertheless, some elderly individuals enjoy excellent sensory and motor function and display, well into advanced age, balance control comparable to young healthy individuals. This suggests that the decline in stability due to