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AGEING AND POSTURAL STABILITY

FALLS AND POSTURAL STABILITY

Approximately 30 percent of the elderly population sustain a fall each year, constituting an important health problem [16]. Falls have different immediate consequences such as hip fractures, and long-term consequences, ranging from restriction of activity to institutionalization [16, 21]. Postural instability is strongly associated with falls and is the best single predictor of falls. Postural reactions in response to external perturbations are essential for maintaining equilibrium [13]. From the theoretical point of view (Lapunov's stability theorem) stability is a feature of any system in which sufficiently small changes in the input parameters result in limited changes of the output. Consistent with this definition is the assumption that a stable postural control system is characterized by its insensitivity to changes in the input (in this case, sensory) values that mediate its reactions.

The process of aging is associated with a well-documented decline in the integrity of many physiological systems that participate in the control of postural stability [12, 17, 25]. Age-related neurodegenerative changes in the neuromuscular control and decreased resolution of the sensory inputs result in the sensory signals which are contaminated with greater noise and physiological delays as compared with young healthy subjects [4, 6, 23]. Additional time and attention resources need to be allocated to the postural task when there is a reduction in the available sensory information [12, 14, 19].

In spite of its very different courses the ageing process takes place in each individual. Generally it can be stated that the stability of posture declines with age. This deficiency is due to increasing deficits in the control system including lower sensitivity of the sensory inputs, slowness of central processing and the decreased power of the motor output. These age-related deficits result in compensatory modification of the control. For example, the standard recovery strategies used in normal subjects are modified and adapted to a new physiological context. Such a functional adaptation to somatosensory and vestibular loss has been well documented [12]. These authors showed that sensory deficits altered the type of postural response selected under a given set of conditions, e.g. vestibular loss resulted in a lack of hip strategy, whereas this strategy was increased in the case of somatosensory loss.

The selection of a balance recovery program depends on many factors such as the availability of sensory information as well as physiological and environmental context. In the case of greater balance perturbations, the only potential strategy to recover equilibrium is to take a step or grab onto a stable object, since the ankle or hip strategies might not be successful any more. The relative strength of the perturbation and the selection of an appropriate corrective strategy depend on the quality of postural control, which declines dramatically with age [12], whereas the effectiveness of ankle and hip strategies depends on stance symmetry. The tendency for the step strategy is evidenced by limb load asymmetry, which helps to initiate a step [10]. Complex impairment of the postural system in the elderly increases the relative strength of a postural perturbation. Thus, one could expect a preference for the step strategy to increase with age as indicated by an asymmetrical limb load distribution.

HEURISTIC MODELS OF POSTURAL STABILITY

The control of the postural stability can be viewed as triple-input and single output system. Proprioception, vision and vestibular system, are the main sources of

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information on the position of the body in space as well as its motion. The output of the control is the position of the center-of-gravity (COG) within the base of support. It has long been understood that sensory information from somatosensory, vestibular, and visual systems is critical for postural control [13]. The vestibulo-spinal reflexes participate in postural control and equilibrium function, and mainly involve stimulation of the otoliths. The sensitivity of the otolith response is emphasized by the fact that in man the threshold for perception of linear acceleration is about 0.005 g.

Most of the studies showed that vision intervenes only in the low-frequency range from 0 to 0.2 Hz [1]. Low frequency postural oscillations observed during experiments with eyes closed were reduced by 50% when the subject's eyes were open. The maximal sensitivity of the visual system to a visual stimulation was noticed for the frequencies of 0.1 up to 0.3 Hz. [15]. The visual system was found to intervene in postural control with greater latency. For example, the visually induced changes in EMG leg muscle activity was 0.5 s. Changes in the subjective vertical occurred after 1 to 2 seconds [11].

The upright posture is defined by mutual relationships of the body segments and the global, vertical orientation of the body in the gravitational field. Such orientation in addition to a narrow base of support and multi-segmental body architecture determines a potential instability of the posture. The classical definition of the postural stability is based upon the COG position and its displacements within the base of support [6]. Only due to an active control of the COG position in space, and particularly in respect to the psycho-physiological stability boarders, the system remains stable [6]. The nature of the control i.e., nonlinearities of the neuromuscular control causes that COG is not maintained in a single point in space but oscillates around it. These tiny movements have been described in literature as a postural sway. In the research on postural control an easy accessible sway component, the center of foot pressure (COP) is usually exploited. Thus, the COP reflects not only characteristics of the COG excursions but also exhibits properties of active signals used in the control of equilibrium. As it can be expected the COP signal may give a better insight into quality of the equilibrium control. This hypothesis gained a strong support from the studies of Sheldon (1963). He first showed that the inability to control sway in the elderly is a major cause of their postural instability. Postural instability is a commonly accepted risk factor, which contributes to falls in the elderly.

The COP excursions have been used by several authors to study the limits of postural stability. The studies that examined these limits as a function of age found the excursion of COP towards the anatomically defined limit of the base of support to decrease with age and pathology [6]. By definition, a person irrevocably loses balance during quiet stance when his/her center of mass falls outside of the base of support (BOS) (for review see [6]). Briefly, to remain in quiet stance the subject must make a stabilizing corrective action prior to reaching the limit of the BOS. At this point in quiet stance the subject must begin a balance recovery program. At some point nearer to the limit of the BOS the only corrective action which may be taken is the more dynamic type of movement (take a step or grab onto a stable object). Knowledge of where in the area circumscribed by the BOS these different types of corrective actions occur may give insights into the physiological correlates of postural stability and its change with age and pathology.

The COP data were also analyzed using different nonlinear dynamic methods. The change in the control has been confirmed by analysis of the sway fractal dimension (Df). In the elderly while standing with eyes closed, the mean Df of the anteroposterior COP was increased from 1.57 ± 0.13 up to 1.63 ± 0.16 [10]. Differences were found both in the maximum (peak) value and the amount of time spent by COP in the preferred position [8]. The maximum value of spatial histogram while staying with eyes closed (6.31 + 3.1 %) was significantly lower than that observed during quiet standing with eyes open (9.91 + 2.6 %).

COMPENSATORY STRATEGIES

With the progression of ageing processes, the stability of upright posture rapidly declines and different compensatory strategies are developed. Such compensation may also involve changes in the hierarchy of different recovery strategies [12], which is evident in the elderly. Studies on forward fall showed a significant increase of the reaction time (around 8-10 ms) in the elderly [20]. Generally, the only way to reduce time necessary to regain balance – in face of progressive impairment of most, if not all, physiological mechanisms – is a modification of the posture (preparatory corrections) that allows making a faster step. We propose that the main compensatory mechanism affects the functional hierarchy of the recovery strategies. Whereas in young healthy subjects the ankle strategy is the first and primary response to a weak postural perturbation [12, 20], a stepping strategy is preferred by the elderly. This can be expected from the gradual decrease with age in the strength of the ankle stabilizers, which is likely to be an important determinant of postural stability.

By reducing the number of recovery programs or by pre-selecting one, the elderly may perform the balance control much faster than it would be expected from the impairment of the postural control system. It has been shown [18] that the elderly can perform quite well in single-reaction motor tasks, whereas multi-choice reaction time is much longer compared with young subjects. A longer selection time might cause a significant delay in implementing the balance recovery program and thus greatly contribute to postural instability. To reduce the effect of this deficiency the nervous system may preselect the recovery strategy (e.g., by preparing a preferred leg for making a step). In this case a typical balance recovery program is reduced from a typical multi-choice task to a single-choice one.

Postural stability in the elderly is altered at least for two reasons. The range of postural sway around the normal COP position has been shown to increase in old adults, thus postural sway will be a greater percentage of the area of stability in the elderly especially in the eyes closed conditions. The increase of COP oscillations may result in the decline of sensory acuity due to decreased signal-to-noise ratio [5, 23] which impairs the detectability of both the normal COP position and stability limits. An increase of the noise level at the input of any control system causes the decline of the information detection and perception [5]. Therefore, the increased sway level might result in additional delays in the sensory systems and, as a consequence, in the increase of postural instability. Studies with induced losses of peripheral sensory information in normal young subjects seem to support our hypothesis. On the other hand, an adjustment of the sensory threshold as the effect of elevated noise cannot be excluded (stochastic resonance). Increased noise in the postural system may also affect the speed of other neuronal processes involved in the recovery program and thus further limit dynamic postural stability. In this context, the characteristic slowness of movement seen in the elderly could be a “strategy of choice” to avoid disequilibrium (uncontrolled pass of the stability border).

They appear at different levels of postural control and are needed to optimize control. An example of such a compensatory modification is the leaning posture observed in the elderly [12], which corresponds to an anterior shift of the normal COG position within the base of support, which improves stability [3, 4]. As observed in our experiment, asymmetrical weighting is another example of a compensatory postural adjustment. We suggest that unloading one limb increases the probability of regaining equilibrium; this strategy reduces the time necessary to complete the 'take a step' balance recovery program. The improvement is due to a reduction in the program preselection and step initiation times.

Efficiency of postural balance control depends on a limited time required to complete the equilibrium recovery program [6]. This time increases with age (for review see [12]) causing substantial delays in control. Undoubtedly, impairments and limitations in any of the elements involved in the sequential process of balance recovery must result in changes in the ranges of stability [6]. Therefore, to be effective, the postural system must initiate a stabilizing action before the COG reaches the border of stability [6, 12, 20]. Considering only biomechanical constraints, the upright posture would be maximally stable when the load is equally distributed between limbs. Such symmetry provides equal probability of balance recovery in every direction. In young normal subjects with a wide margin of stability, the symmetry would result in an equal (but not necessarily the shortest) time needed to complete a recovery program in every direction.

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