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IDENTIFICATION OF AGING EFFECTS ON THE CONTROL OF UPRIGHT STANCE USING A LOCAL MAXIMUM WAVELET TRANSFORM METHOD

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The purpose of this study was to investigate aging effects on the mechanisms of postural control during upright stance, and specifically the use of proprioceptive feedback on this control. Thirty-two healthy individuals participated, equally divided among younger (19-22 years) and older groups (54-68 years) and genders. Experimental trials involved several sessions of quiet stance on a firm surface with eyes closed. Center of pressure (COP) data were obtained from a force platform and processed using a new local maximum wavelet transform method. The critical time interval (CTI) derived from this method was proposed to describe the activation period of proprioceptive function, which is mainly influenced by the proprioceptive feedback loop. A reduced CTI was assumed to indicate poorer control based on proprioceptive input. Results showed that younger participants' CTI significantly increased from the first experimental session to consecutive experimental sessions in both the mediolateral (ML) and anteroposteriorer (AP) directions. However, older participates' CTI did not exhibit significant differences between the first and the consequent experimental sessions in either direction. This result suggests that the adaptability of proprioceptive function was impaired with age. Younger adults' CTIs were significantly larger than those of older adults in both ML and AP directions, indicating that among older adults stance control based on proprioceptive function was significantly impaired due to aging.

1. INTRODUCTION

Progressively impaired peripheral sensation that occurs with age appears to relate to and be predictive of fall risks among the elderly (e.g. Lord et al. 1991; 2001). In their systematic review, Stelmach and Worringham (1985) highlighted that the age-related decline in proprioception (the interoceptive sense of body position) is one of the principal sensorimotor and central processing deficits among older adults. Therefore, determining the effects of age on proprioception and its consequences may be crucial in understanding aging effects on posture control and preventing falls among older adults.

Declines in proprioceptive function with age have been demonstrated in several studies. Proprioceptive function can be regarded as the sensitivity and acuity of sensing limb position and movement. Hurley et al, (1998) revealed that age-related deterioration in sensorimotor function of the quadriceps muscle as well as the decline of proprioceptive function may, as a result, contribute to the increased fear and frequency of falls in elderly subjects. Shaffe and Harrison (2007) noted that preferential loss of distal large myelinated sensory fibers and receptors and impaired distal lower-extremity proprioception, vibration and discriminative touch, and balance are two types of pronounced age-related proprioceptive function declines.

Petrella et al. (1997) concluded that proprioception is diminished with age by measuring errors between the reproduced angle and the specified angle with young and older participants' dominant knee joint. Decline of proprioception with age were also reported by Pai et al. (1997) and Skinner et al. (1984) based on detection of knee joint displacement, motion and ability to reproduce passive knee position. Creath et al. (2005) investigated the effects of proprioception on upright stance with participants standing on foam surfaces and a rotated platform and showed that mechanisms of posture control was shifted from an in-phase to anti-phase manner because of proprioception changes. Despite this evidence related to joint angle reproduction and upright stance stability, however, the specific relationship between posture control and impaired proprioception due to advancing age still remains unclear.

In the current study, the main objective was to quantify the effects of aging on proprioceptive function with a protocol that is straightforward, reproducible, and clinically applicable. Posturograms (COP time series) obtained during upright stance were used to assess aging effects on proprioceptive functions. A primary hypothesis was that the adaptability and controllability of proprioceptive functions to control upright stance become significantly worse with advancing age.

2. METHODS

2.1. Experimental Procedures

The experiment involved five sessions, separated by at least 24 hours, during which participants performed several trials involving quiet upright stance. Data analyzed here were from three trials on each day that were done on a hard surface, with eyes closed, and participants instructed to stand as still as possible. Trials lasted 75 seconds, during which triaxial forces and moments were obtained from a force platform (AMTI OR6-7-1000, Watertown, MA, USA). These were sampled at 100 Hz, low-pass filtered (5Hz, Butterworth, 2nd order), demeaned, and used to obtain the center-of-pressure (COP) time series in the antero-posterior (AP) and medio-lateral (ML) directions.

2.2. Participants

Sixteen younger and 16 older individuals participated, with an equal number of males and females in each age group. All participants completed an informed consent procedure approved by the Virginia Tech (institute review board) IRB, and had no self-reported injuries, illness, musculoskeletal disorders or falls in the year prior to the study. Table 1 provides summary descriptors of the participant population.

Table 1: Participant characteristics (n=16 in each group)

	Age (years)	Stature (cm)	Body Mass (kg)
Younger Adults	20.7 (1.6)	171.2 (7.2)	66.2 (11.6)
Older Adults	63.2 (5.6)	167.8 (10.9)	77.6 (18.4)

2.3. Critical Time Intervals of Proprioceptive Functions

Mallat & Hwang (1992) proposed the local maximum modulus wavelet transform method, which is particularly well adapted to estimate the local regularity of functions. They proved that all singularities (local maximum) of arbitrary functions can be detected by the local maximum modulus wavelet transform method. Here, the local maximum power spectrum wavelet transform method was adopted to detect the local maxima of power spectra, where a power spectrum is the square of wavelet modulus.

The wavelet transform is given by:

$$WT(a,b) = |a|^{-1/2} \int f(t)\varphi\left(\frac{t-b}{a}\right)dt \qquad (1)$$

where b is the translation parameter and a is the scale (frequency). $WT(a,b)$ is the wavelet coefficient. φ is the Coiflets wavelet function, which was found to be the most effective at reducing low frequency distortion for COP data.

The power spectrum PS(a,b) is defined by:

$$PS(a,b) = |WT(a,b)|^2 \qquad (2)$$

It has been shown (Thurner et al., 2000) that somatosensory activity is evident in the COP frequency band of 0.5-1.0 Hz. In addition, previous studies (Blaszczyk et al., 1993; Stelmach and Worringham,1985) have shown that aging mainly compromises proprioception. Hence, the COP frequency band of 0.5-1.0 Hz was used in power spectrum analysis to identify aging effects on proprioceptive control. A local maximum line L_t was defined as the line comprised of the local maxima identified at time t across frequency bands from f1 to f2 Hz. This local maximum line can be described as:

$$L_t \overset{d}{=} \{PS(f,t), f = f1 \cdots f2\} \qquad (3)$$

The local maximum line was identified around time t within a $2\Delta t$ interval [t- Δt , t+ Δt]. Time interval Δt used to search for the local maximum line was determined heuristically. The searching time interval Δt was specified to be 0.21 second, which was obtained by gradually increasing the Δt value from a very small value (e.g., 0.05 second) until a reasonable number of local maximum lines was obtained across the entire frequency band of 0.5-1.0 HZ

There exist a series of intervals $\Delta L = \{\Delta L_{t1}, \Delta L_{t2}, \ldots, \Delta L_{tn}\}$, and the interval ΔL_{ti} was defined as:

$$\Delta L_{ti} = t_{i+1} - t_i \qquad (4)$$

where t_{i+1} and t_i corresponded to the time when $L_{t_{i+1}}$ and L_{t_i} were identified.

The critical time interval $\langle \Delta L \rangle$ was defined as the mean of ΔL. The time interval Δt was used to search for the local maximum line L_t, and the local maximum line interval ΔL_t. Figure 1 shows an example, in which it is apparent that the first two local maximum lines are at time t1 (5 seconds), and time t2 (6.5 seconds). ΔL_{t1} is the local maximum line interval between time t_1 and t_2, and Δt is the length of the interval used to search for the local maximum line.

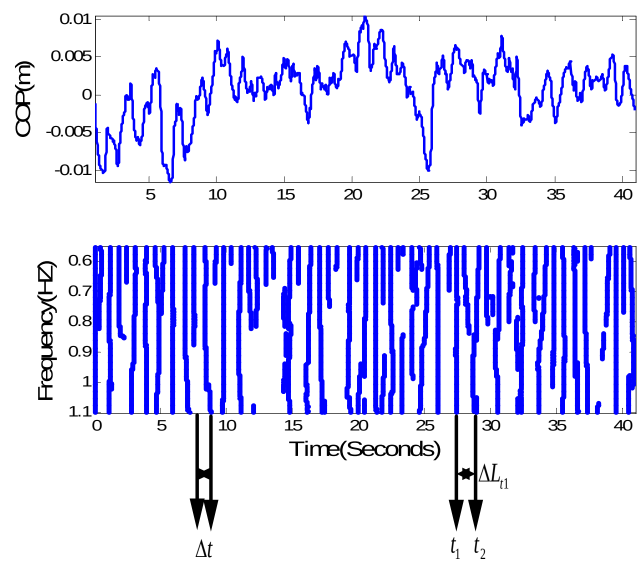

Figure 1: Local Maximum lines and local maximum line intervals

An overview of the algorithmic flow used to identify critical time intervals is shown in Figure 2.

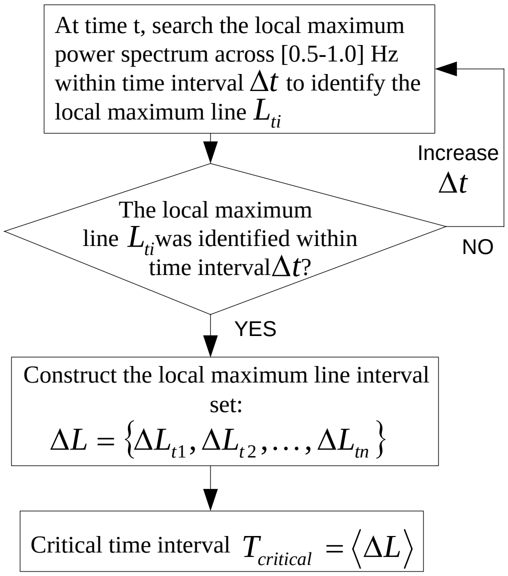

Figure 2: Algorithm used for identification of the critical time intervals

2.4. Statistical Analysis

Two-way repeated-measures analysis of variance (ANOVA) was performed to test the aging and proprioceptive function adaptation effects on CTIs. Independent variables were age (younger and old), and session (five levels, each session treated as one level). The dependent variable was the critical time interval (CTI) of proprioceptive functions. The level of significance was set at $p<0.05$.

3. RESULTS

3.1. Critical Time Intervals for Younger and Older Adults

ML and AP CTIs for younger and older adults are shown in Figure 3 and 4, respectively.

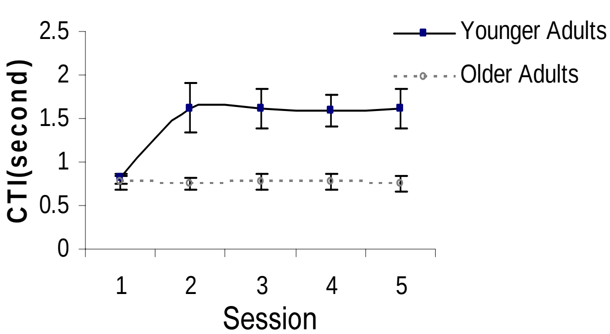

Figure 3: Critical Time Intervals for Younger and Older Adults, ML direction

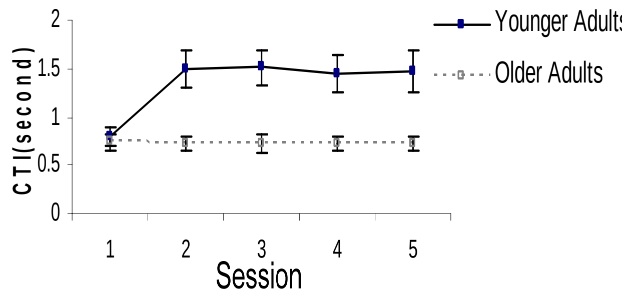

Figure 4: Critical Time Intervals for Younger and Older Adults, AP direction

Among younger adults, CTIs dramatically increased from the first to the second experimental sessions in both the ML and AP directions. In contrast, CTI from the first experimental session CTI among the older adults was not significantly different from the second experimental session in either the ML ($p = 0.058$) or AP ($p = 0.78$) directions. No significant differences were found among pairwise comparisons of CTIs from sessions 2–5 among either the younger or older participants. CTIs from the older group were significantly smaller than those of the younger group in sessions 2–5 in both the ML and AP directions.

4. DISCUSSION

The CTI of proprioceptive functions corresponds to the time interval of fully activated proprioceptive function, which is used in order to stabilize upright stance. The increase of older adults proprioceptive function frequency might be driven by the recruitment of additional motor units and/or an increase in motor unit firing rates of the soleus muscles during upright standing. Theoretically, biomechanical models of upright stance (e.g. Johansson et al. 1995) have shown reduced performance of proprioceptive receptors among older individuals, which leads to an extended time delay in feedback control. In order to compensate for such extended time delays in the context of balance maintenance, the firing rates of soleus muscles were increased. The observed increase of proprioceptive control frequency from this study is indirectly consistent with the research findings of Blaszczyk et al. (1993) and Melzer et al. (2004). These authors used sway range methods (e.g. COP path), and found that the COP path among older adults is significantly larger than that of younger adults on specific standing surface (e.g. foam) conditions. A larger COP path often corresponds to a higher COP frequency due to the bounded COP magnitude for both younger and older adults. Empirically, our research found that the higher frequency COP usually induced an increased proprioceptive function activation frequency due to the increasingly identified quantity of local minimum and maximum in higher frequency COP.

Considering the fact that a higher CTIs frequency implies a decline of proprioceptive functions, it is apparent that with larger CTIs, which corresponds to a lower CTI frequency, a greater ability to control upright stance was demonstrated. The significant increase of CTIs from the first to the second experimental session indicated an adaptability among younger adults to specific external proprioceptive inputs e.g., the force platform. The improved adaptability of younger adults might be associated with the learning effects within the central nervous system (CNS) and enhanced proprioceptive functions as a result. Huang et al. (2006) pointed out that CNS is able to integrate external input information and associate the sensory patterns with motor actions. Such CNS internal representations may lead to facilitated efferent speed of proprioceptive functions. In contrast, older adults did not adapt to external proprioceptive inputs as well as younger adults, and did not show any clear increase of CTIs across sessions. This result was indirectly consistent with the finding of Maki et al. (1999), who reported that younger adults are more able to recover balance without stepping following a rearward directed perturbation.

Younger adults' proprioceptive control CTIs were significantly larger than those of older adults, indicating support for our hypothesis. As a result, we may conclude that impaired proprioceptive function due to aging contributes to fall risk among older adults. This is also consistent with other studies (Blaszczyk et al. 1993; Lord and Webste 1990; Stelmach and Worringham 1985; Melzer et al. 2004), which have demonstrated that proprioception is markedly impaired due to aging. In addition, Lord et al. (1999) and Maki et al. (1999) indicated only lateral spontaneous sway can be used to predict future falls, whereas our results showed that both ML and AP were impaired significantly due to aging. Thus, the underlying physiology mechanisms accounting for the age-related increase of CTIs need to be further investigated.

5. CONCLUSIONS

In this study, we have identified proprioceptive function differences between younger and older adults during quiet upright stance on a firm surface with eyes closed. With a new local maximum modulus wavelet transform method, we calculated CTIs of proprioceptive functions from COP data. It appeared that there is a clear threshold separating younger and older adults' CTIs, where older adults' CTI frequency was significantly larger than that of younger adults, indicating impaired proprioceptive functions due to aging. It was also found that younger adults had a higher ability than older adults to adapt to the experimental environment following a single session of exposure.

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