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A Model-Based Approach To Attention and Sensory Integration in Postural Control of Older Adults

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***Abstract*— We conducted a dual-task experiment that involved information processing (IP) tasks concurrent with postural perturbations to explore the interaction between attention and sensory integration in postural control in young and older adults. Data were fit to a postural control model incorporating sensory integration and the influence of attention. This model hypothesizes that the cognitive processing and integration of sensory inputs for balance requires time, and that attention influences this processing time, as well as sensory selection by facilitating specific sensory channels. Differences in the time delay of the postural control model were found for age and IP task, suggesting enhanced vulnerability of balance processes in older adults to interference from interfering cognitive IP tasks.**

I. INTRODUCTION

Falls are a significant problem in older adults, resulting from a complex interaction of sensory, motor and cognitive loss. Recent research has found that attention plays a role in postural control [1], [2], [3], as does dynamic regulation of sensory integration [4], [5], [6], [7]. However, the interaction between attention and sensory integration is an open question. This paper addresses the incorporation of the interaction of attention and the dynamic regulation of sensory integration into models of postural control.

A postural control model incorporating sensory reweighting sets forth a quantitative framework for exploring this process [6], [7]. We explicitly added a cognitive component (i.e., attention) to the model. In this model (Fig. 1), attention influences sensory integration primarily through the time delay parameter t_d and the sensory weights. This model hypothesizes that the processing and integration of sensory inputs for balance requires time, and that attention influences this processing time. Dual-task paradigms explore attentional processes involved in sensorimotor function by requiring subjects to perform two tasks simultaneously. Degradation in performance of either task is believed to reflect competition for cognitive resources (i.e., attention). In postural control dual task experiments, one generally combines a "balance" task (such as standing, or responding to a perturbation) with a cognitive task (such as reaction time task, mental arithmetic, visuospatial memory task, or word recall). In this study, a dual-task experiment was conducted to examine competition for cognitive resources and its impact on a model of postural control through increase in sensory processing time, quantified by the delay time parameter in the model. Least-squares model fits to subject data were made to quantify differences between young and older adults.

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II. METHODOLOGY

A. Experimental Protocol

Ten healthy young adults (M=5, F=5, 25±3 yrs.) and five older adults (M=3, F=2, 73±9 yrs.) participated in this study, with their IRB-approved informed consent.

Subjects stood, while performing IP tasks, with eyes closed and arms folded across their chest on an EquiTest posture platform that rotated randomly for 121 sec about an axis collinear with the ankle axis. Platform motion was preceded and followed by 30 seconds of no platform motion (Fig. 2). The eyes closed condition was chosen to enhance the postural challenge, to simplify the sensory integration and sensory re-weighting strategy for modeling (presumably limited to proprioceptive and vestibular channels), and to focus attentional resources on fewer sensory channels. Three trials per subject per IP task were conducted, and subjects performed the IP task throughout the 181 sec trials. IP tasks were performed on different days.

The IP tasks were: 1) None, 2) an auditory choice reaction task (CRT), in which subjects pressed a hand-held microswitch with either the left hand or right hand depending on whether they heard a high or low tone (980 Hz or 560 Hz, duration 250 msec, intensity 80 dB SPL, mean interstimulus interval of 4 sec), and 3) an auditory vigilance task (VT), in which subjects had to remember the number of high or low tones heard during the trial. Subjects were trained in the IP tasks prior to testing. Platform movement and anterior-posterior hip position were recorded, from which least-squares fits to the postural control model were made, analogous to [6].

B. Postural Control Model

The postural control model used in this research is based on the sensory re-weighting model of Peterka [6]. We modified the model and apply predicted functional consequences of sensory re-weighting (Fig. 1). The transfer function of the model for the body sway (BS) in response to support surface (SS) motion is given by

$$\frac{BS(s)}{SS(s)} = \frac{W_P(K_D s^2 + K_P s + K_I)e^{-st_d}}{Js^3 - mghs + \mathbf{W}(K_D s^2 + K_P s + K_I)e^{-st_d}}, \qquad (1)$$

where W_p is the proprioceptive sensory weight, which according to the sensory re-weighting hypothesis can change with environmental conditions; t_d is the overall time delay that includes neural conduction times as well as cognitive processing time; and K_P, K_I and K_D are the fixed gains of a PID controller that generates the corrective ankle torque T_a to maintain upright balance. The parameters K_P and K_D represent the active stiffness and damping, respectively, of the postural control system. The parameter $\mathbf{W}$ represents the total sensory contribution, which during eyes-closed stance is $W_p + W_g$, and under steady-state is taken to be $\mathbf{W} = 1$.

III. RESULTS

Model fits were conducted similar to [6]. Specifically, smoothed experimental frequency response functions between the rotational platform movement and the hip sway were computed for each subject, per IP condition, and then a least-squares fit to the model of (1) was made. The model fits produced five parameters $[W_p, K_P, K_D, K_I, t_d]$ per subject per IP condition. The same initial values of the model parameters were used for all model fits. A sensitivity analysis to initial values was conducted by changing each of the initial parameters by $\pm 20\%$. Over 240 (3^5) combinations of initial parameters were tested, resulting in convergence to the same final parameters to within 1%.

The time delay of the postural control system increased during concurrent IP and postural challenges for both IP tasks in the older adults; young adults exhibited an increased time delay for only the more cognitively challenging vigilance IP (VT) task (Table I and Fig. 3, left graph, where the percent change in time delay during IP tasks relative to no-IP condition is shown). With the exclusion of one outlier, older subjects were found to have significantly longer time delays during the CRT task compared to no task (p = .03). The one older subject who was removed had a time delay going in the opposite direction of all other subjects, and was 3.5 standard deviations from the mean value of the population. There was no significant effect of the CRT task on the young subjects. There was a significant increase in time delay during the VT task compared to the NONE condition across all subjects (p = .05), with no age effects seen. Older subjects, unlike younger subjects, also exhibited changes in sensory re-weighting during concurrent IP tasks, as manifest by a decrease in proprioceptive weight relative to no IP conditions (Fig. 3, right graph). No changes in the damping (K_D) and integral (K_I) parameters were found with IP condition. Because increased time delay in a control system tends to decrease stability, a compensatory decrease in the active stiffness of the postural control system (K_P) concurrent with the increase in time delay might be expected [6]; however, this relationship was not found to be statistically significant in our limited sample size.

IV. DISCUSSION AND CONCLUSION

These results suggest that our model of postural control, including attentional influences in the time delay, can quantify dual-task interference. The model implies that the

TABLE I

POSTURAL CONTROL TIME DELAY FOR YOUNG AND OLDER ADULTS DURING IP TASKS VS. NO TASK (MEAN± SD)

IP Task	t_d [msec], YOUNG	t_d [msec], OLDER
NONE	153.52±11.98	155.42±11.93
CRT	153.55±18.0	165.34±20.01
VT	161.9±12.98	163.04±12.05

time for sensorimotor processing involved in maintaining balance is a focus of that dual-task interference. This result is consistent with the notion that a specific aspect of attention, namely executive function, is the primary component involved in this interference. The similarities and differences between age groups in time delay changes suggest that healthy older adults have similar postural control function as young adults during mild postural challenges without concurrent IP tasks, but different postural control function during dual-task conditions. These differences likely reflect the enhanced vulnerability of balance processes in the older adults to interference from cognitive processes. The results also suggest that certain perceptual-motor tasks requiring speeded motor responses (i.e. pushing a button in response to a stimulus) slows balance processing in the old but not the young.

Furthermore, the changes in sensory weighting suggest a potentially significant strategic shift in posture control in the elderly that calls for further investigation. This finding regarding sensory re-weighting during IP task in the older subjects but not the young subjects can be interpreted in terms of the idea proposed in [2], that attention influences sensory selection. In particular, attentional resources drawn to the auditory task serve to enhance the auditory channel. If older adults have greater limits on cognitive resources compared to young adults as evidence suggests, then this shifting of attention to enhance one sensory channel comes at the expense of other sensory channels, namely the proprioceptive channel in this case. This decrease in the proprioceptive weight would also have a stabilizing effect, as it would reduce the influence of the platform perturbation coming in through the proprioceptive channel (SS in Fig. 1). This, too, is consistent with previous findings that older adults are challenged to a greater degree to postural perturbations compared to young adults [2].

In conclusion, this initial study supports the main postulate of our model, that attention, in part, impacts processing speed of the sensory integration process. This effect appears to be true across ages under some conditions (i.e. during our VT task), but greater in older adults under other conditions (i.e. during our CRT task). Further studies in a larger population are warranted.

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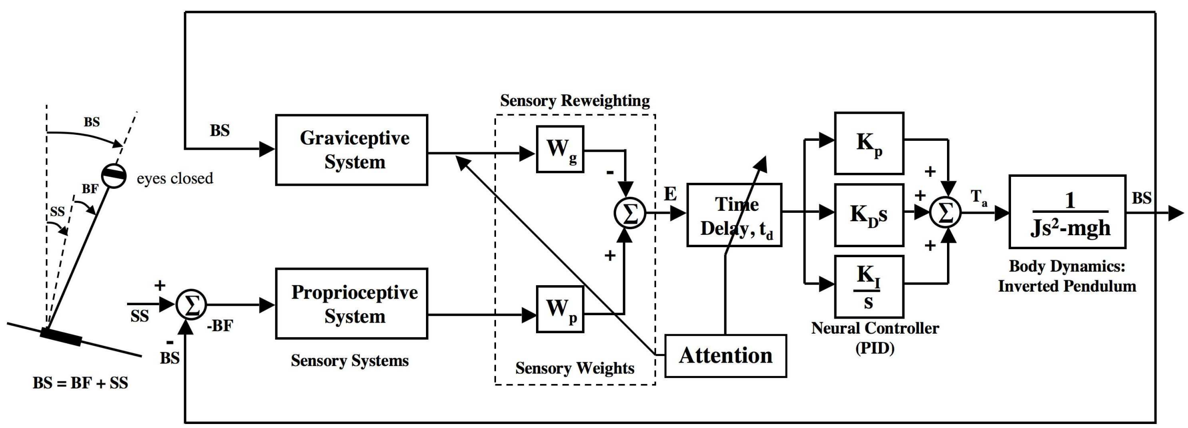

Fig. 1. Feedback model of postural control for eyes-closed stance. The body is modeled as a linearized inverted pendulum. Sensory pathways include weights (W_g, W_p) that can change as environmental factors change (the "sensory re-weighting" hypothesis). Corrective ankle torque, T_a, is generated by a fixed-gain proportional-integral-derivative controller acting on the combined delayed error signal E from the sensory systems. Attentional tasks that interfere with balance are hypothesized to increase cognitive processing time involved in balance, manifest in the model as an increase in the time delay of the system. Attention may also influence sensory integration, as manifest in the model via the sensory weights (W_g, W_p). Modified from [6], [7].

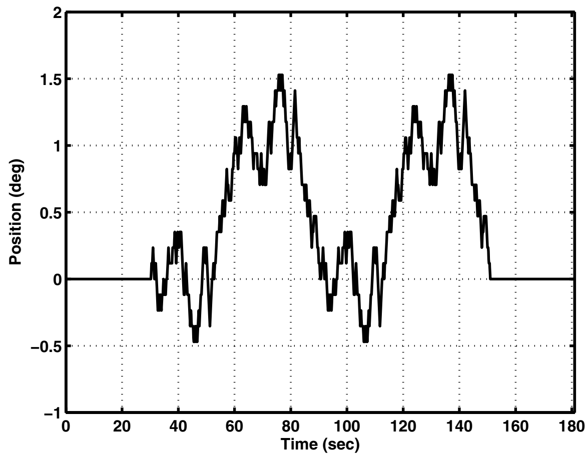

Fig. 2. Platform motion (position) used in the experimental protocol, consisting of two 60.5 second cycles of a pseudorandom ternary sequence (PRTS) with 2 degree peak-to-peak amplitude, preceded and followed by 30 seconds of no platform motion.

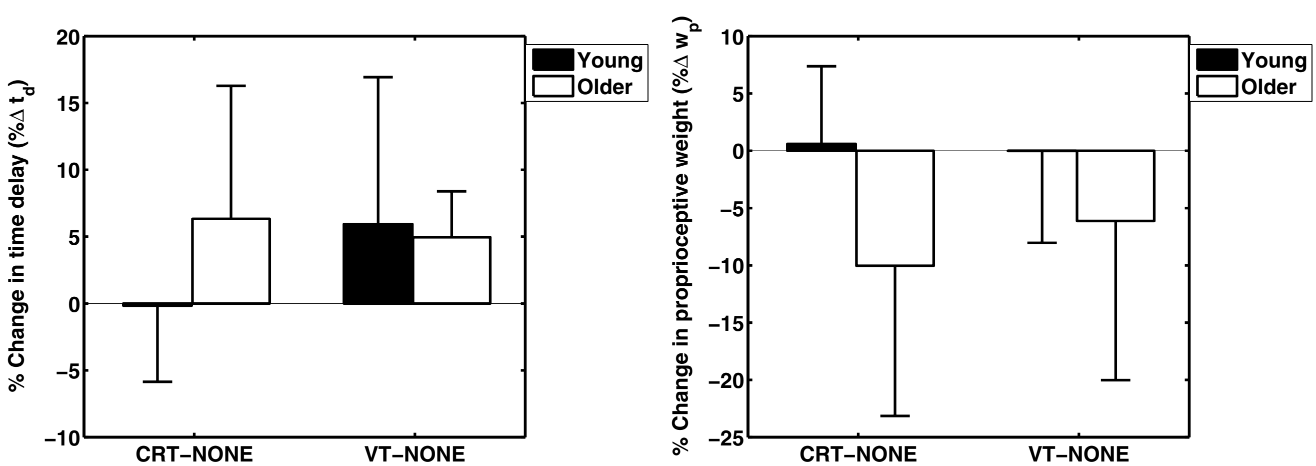

Fig. 3. Percent change in postural control time delay (left graph) and proprioceptive weight (right graph) (mean±sd) during IP tasks relative to no-IP task condition (CRT-NONE and VT-NONE), for young (black) and older (white) subjects. The postural control of older subjects was affected by both IP tasks, as manifest by increased time delay in the postural control model fit to data, whereas the CRT task had no affect on postural control in young subjects. Older subjects exhibited sensory re-weighting during the IP tasks, while younger subjects did not.