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Psychophysical Detection Thresholds in Anterior Horizontal Translations of Seated and Standing Blindfolded Subjects

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Abstract— **To help separate out the contributions of the somatosensory and vestibular systems to postural and sway control, short (1, 4 and 16mm) anterior translations of lengths less than the normal sway path length were made of a platform upon which blindfolded young adult test subjects (n=12) stood or sat. Acceleration detection thresholds from these short moves were compared in standing vs seated conditions using a 2- Alternative [Interval] Forced-Choice psychophysical test protocol. A negative power law trading relationship was found between peak acceleration threshold and move length and duration for standing subjects. For these same subjects while seated, acceleration thresholds for all lengths were nearly constant, and showed a weak positive power law trade between threshold and move length or duration. This latter observation is consistent with that of Benson et al '86, who also observed a positive power law trade relationship between acceleration threshold and move duration for seated subjects. Thresholds were higher at 1mm for standing vs. seated tests; while at 16 mm, standing tests had lower thresholds compared to those obtained for the seated tests. These results suggest that the vestibular system provides the principal input for detecting these short translations while seated, but not while standing.**

I. INTRODUCTION

Many tests of postural stability use large perturbations whose magnitudes are far greater than the unperturbed natural sway path length. Our postural control study uses short translational perturbations on the order of a few 10s of mm (1mm, 4mm, 16mm), chosen to be near or less than a person's natural sway length while standing. These short perturbations can be compared to the cm length moves used by most other studies. Thus, our approach is a significant new way to explore postural control in the elderly and those with diabetes. We get a far better feel for the control mechanisms of normal sway, and how they are modified by age, disease or trauma. Our low-vibration (SLIP-FALLS-STEPm system (Sliding Linear Investigative Platform for Analyzing Lower Limb Stability with Synced Tracking EMG and Pressure measurements) is used to study the psychophysical, biomechanical and neurophysiological responses to short horizontal perturbations that are at the edge of perception.[1]

Psychophysics deals with the relationship between a stimulus of known strength and a subject's perception of that stimulus [2]. A consistent finding of all our past experiments was that there exists a robust psychophysical negative power law trading relationship between the peak acceleration needed for movement detection (i.e., the threshold) and the move length and duration of the translation [3,4,5]. A 1mm translation required a geometrically higher acceleration than a 16mm translation. But these results were at odds with the psychophysical detection threshold tests done by Benson et al [6] for seated subjects, albeit using a slightly different 2-AFC testing protocol. Thus, we felt it necessary to test a group of 12 blindfolded young adult subjects with our 2-AFC detection test protocol both while standing (harnessed) and while seated (restrained). The resultant power law trading relationships between peak acceleration detection threshold and perturbation length or duration for both standing and sitting tests are discussed here, as are how the findings relate to postural control.

II. METHODS

A. Standing and Sitting Test Protocols

Psychophysical techniques are employed here as an effective way to measure the signal strength necessary for detection [2]. Threshold is defined as the peak acceleration amplitude at which at least 75% of the translations were correctly detected by a subject, while standing on, or sitting on a chair on, the translating platform as it underwent small (1, 4, and 16mm) forward horizontal moves during each trial [2].

The same 2AFC (2 Alternative Forced Choice) protocol was used during all standing and sitting trials. In each 2AFC trial, a stimulus was presented in interval 1 or 2, and the subject was required to indicate in which interval (s)he detected the platform move [3]. Each standing or sitting run included a maximum of 30 2AFC trials (to prevent subject fatigue [3]) each at fixed platform displacements of 1, 4 and 16mm. A modified iterative Parameter Estimation by Sequential Testing (mPEST) technique was applied through all 30 trials

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to iterate acceleration to threshold based on the correctness of preceding trials [3]. The 12 young adult subjects tested were blindfolded during all tests, and commands and masking noise were delivered via headphones. If standing, they wore a non-weight-bearing harness for safety and were asked to stand quietly during all trials to avoid large postural changes and excessive body sway. Seated subjects had their torsos and heads restrained to the back of the padded chair.

B. SLIP-FALLS Platform and Data Processing

These tests used our Sliding Linear Investigative Platform for Analyzing Lower Limb Stability (SLIP-FALLS). The SLIP-FALLS glides on vibration-free air bearings to reduce vibration [1]. Platform position control was achieved within 5µm via a linear motor and optical position encoder. Acceleration values were iterated depending on the correctness of detection, and could range from 256 to 0.98 mm/s^2 (26 to 0.1 mG). An accelerometer on the platform verified that the commanded and actual acceleration values were within 1% of each other. Further details of the platform design and testing protocol can be found in [1,8].

While this paper only focuses of psychophysical results, data were collected from lower limb EMGs, triaxial head accelerometer, platform position encoder and accelerometer, platform and harness loads cells at a 1000Hz sample rate [9] for analysis of physiological correlates of detection[7,11,12].

III. RESULTS

A. Results from Blindfolded Subjects Standing vs. Sitting

We compared sitting vs. standing thresholds from 12 healthy blindfolded young adults. Figures 1A,D plot the thresholds for each of these subjects as a function of movement lengths of 1, 4 and 16mm. In those figures, subjects were sorted by their thresholds to 16mm excursions in the seated and standing tests, respectively. Note that PAT_{1mmStd} was always > $PAT_{16mmStd}$ (Figure 1A); and that in in all but 2 occasions, PAT_{4mmStd} fell between these two thresholds. In contrast to the standing data, 9/12 subjects while seated had $PAT_{1mmSit} < PAT_{16mmSit}$. By comparing the end of the $PAT_{16mmStd}$ plot with the beginning of the $PAT_{16mmSit}$ plot, it appears that the 16 mm thresholds were almost always lower while standing than sitting. This is confirmed in Fig. 2A, where within-subject comparisons showed that $PAT_{16mmStd}$ was always less than $PAT_{16mmSit}$. Also note that for the most part $PAT_{1mmSit} \leq PAT_{1mmStd}$, as was also shown in Fig. 2A. Standing thresholds for the same subject were not predictive of seated thresholds.

The data in Figs. 1A,D, were replotted in Figs. 1B,E on a log-log scale to show the relationship between Peak Acceleration Threshold (PAT) and move length for each subject. A plot of the geometric mean of the standing data yielded a *negative* power law relationship of the form:

$$PAT = 49.9 \times DISPL^{-0.60} \qquad \text{Eq.1}$$

This equation is similar to one that we reported elsewhere for another group of standing young adult subjects [7].

Finding a representative power law slope in the seated data is problematic given the variety of the individual stimulus - response curves of Figs. 1E,F. The PAT geometric mean of the seated data when plotted (Fig. 1E) yielded a weak *positive* power law trading relationship of the form:

$$PAT = 24.1 \times DISPL^{+0.06} \qquad \text{Eq.2}$$

Similar stimulus-response plots were made of the relationship between movement duration at threshold and the acceleration threshold (Figs. 1C, F), with the geometric means plotted as:

$$PAT = 18.1 \times TIME^{-0.75} \quad \text{(Standing)} \qquad \text{Eq.3}$$

$$PAT = 27.0 \times TIME^{+0.12} \quad \text{(Seated)} \qquad \text{Eq.4}$$

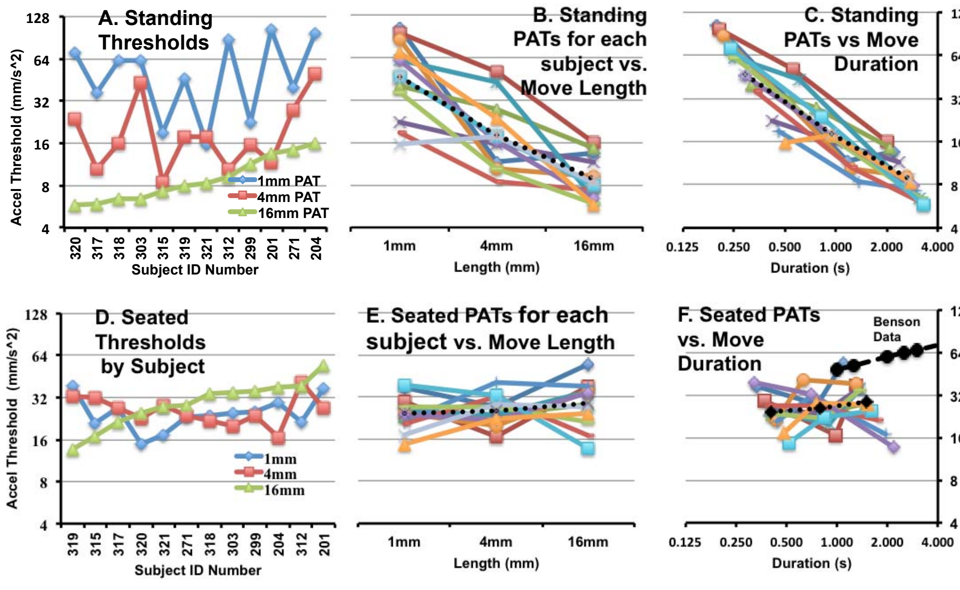

Figure 1. Individual standing [A,B, C] vs sitting [D,E,F] peak acceleration thresholds (PATs) and move durations at threshold from 1, 4 and 16mm anterior translations of blindfolded young adult subjects. **[A,D]:** Subjects sorted by 16mm threshold values. In [A], note that all 16mm standing thresholds are *below* all of those at 1mm, with the 4mm thresholds most often between the two. In [D], the 16 mm seated thresholds are *above* those at 1mm for 9 of 12 subjects, with the 4mm thresholds in between them. **[B,E]:** Log-Log plots of PAT vs displacement length. The geometric mean regression (power law relationship) is plotted as a dotted line. **[C,F]:** Log-log plots of PAT vs move duration, with power laws plotted. The positive power law trade of Benson et al's [6] eyes-closed seated data is included in [F].

A better picture can be gleaned by noting that seated detection thresholds were nearly identical to the standing ones for 4 mm moves, higher for 16 mm, and lower for 1 mm (Fig. 2A). The converse was true for duration — all 16 mm durations at threshold were lower for sitting than standing, with 1 mm standing durations less than or equal to the sitting ones (Fig 2B).

B. Comparing with Benson's sitting test results

Benson, et al [6] carried out a blindfolded seated 2AFC threshold protocol similar to ours, but with some significant differences. Their Experiment 2 found a positive power law trade between PAT and move duration. We reconstructed their power law from an analysis of their Fig. 5 to get:

$$\text{PAT} = 48.9 \times \text{TIME}^{+0.29} \qquad \text{Eq.5}$$

This regression is also plotted in Fig. 1F and 3B. The power law regressions given in Equations 1 to 5 are plotted together in Figs. 3A for displacement and Fig. 4B for duration. Benson et al's data had a similar slope but a larger time offset (Fig. 3B). Because our acceleration profiles differ slightly from theirs (they used a single sinusoid, while we used a smoothed blended profile), the displacements that they used cannot readily be extracted from from their paper or their Fig. 5. We forced our subjects to choose which interval (1 or 2) contained the anterior translation. Benson et al had their subjects signal the direction of a move. But their subjects also were given an additional null choice if they could not discern a direction, which might have made their procedure less sensitive than ours.

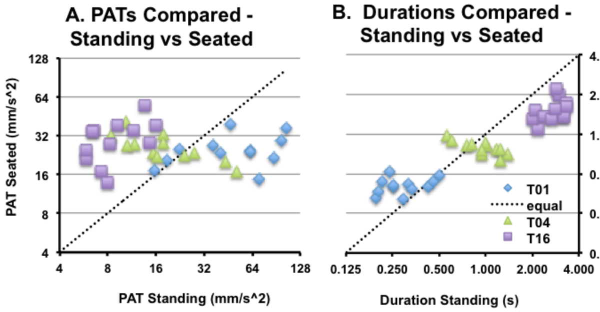

Figure 2. Comparing standing vs seated PATs [A] and threshold durations [B] in 12 blindfolded young adults as a function of 1, 4 and 16mm move distances (represented by diamonds, triangles and squares, respectively). The dotted lines represent equal PATs and durations between seated and standing conditions.

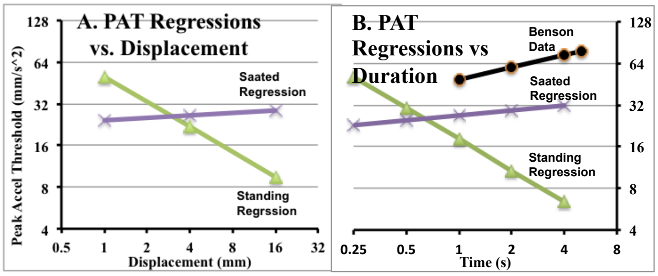

Figure 3. Power law regressions versus Move Length [A] or Duration [B] for standing and seated blindfolded anterior translations. Regressions cross at 25.5 mm/s^2 at 3.04 mm and 0.632 s. Data from Benson et al's [6] experiment is plotted for reference.

IV. DISCUSSION

Identical 2AFC P.E.S.T. iterative methods were used to determine psychophysical detection thresholds to anterior horizontal translations of various lengths of a standing or sitting support surface upon which visually and aurally masked subjects were placed. This allowed for a direct comparison of the stimulus-response curves between the standing and sitting conditions. These S-R curves related peak acceleration threshold (the response) to displacement length and duration (the stimuli).

The starting point for these comparison experiments was the data of Fig. 1B, where all standing subjects had a negative power law S-R relationship. But these results did not jive with the positive power law findings of Benson et al for seated subjects. To corroborate Benson's data using our protocol, we constructed a support chair that could be bolted to the SLIP-FALLS. Like Benson et al [6], we then found a positive trade between acceleration threshold and time (Fig. 3B) when our subjects were seated. Our test results indicated the existence of the fundamental differences in translational detection while standing vs sitting.

Motion perception is mediated by the visual, vestibular and somatosensory sensory systems. By blindfolding our standing subjects and aurally masking ambient noise, they were forced to make detection decisions based only on vestibular and somatosensory inputs. Further, we hoped to eliminate or greatly reduce somatosensory inputs to detection by restraining our subjects in an anteriorly translating chair. And we did find a marked difference in responses between the seated and standing conditions. In many respects, we can hypothesize as did Benson et al [6] that the vestibular system alone provided the only sensory information available to a blindfolded, highly restrained seated subject as (s)he underwent a subtle, very low vibration, anterior horizontal translation at an acceleration near detection threshold. With only vestibular input, thresholds were on the order of 2.5 mG for all subjects and all move lengths.

Herein lies a puzzle. The different thresholds at 1 and 16mm between seated and standing conditions were in stark contrast. The group's 16mm standing acceleration threshold was 4X lower than the seated one (Fig. 6A), and the threshold duration at 4 s is almost 5X lower (Fig. 6B). But the completely opposite thresholds at 1 mm between seating and standing subjects were even more perplexing. The group's 1mm standing acceleration threshold was 2X higher than the standing one (Fig. 6A), while the threshold duration at 0.25 s was also about 2X higher (Fig. 6B). One might have predicted that the standing curves should have had breakpoints at the 3mm and 632 ms crossover points, so that above those values the standing regressions are followed; and below them, the seated thresholds.

But we know from past studies on young adults that the standing regression PAT vs length curve continued straight to at least a 0.25mm move [3,10]. And we now know from our ongoing newer studies that seated thresholds indeed appear to be lower than for standing ones for 0.5mm moves. It is almost as though the vestibular input was turned off during normal standing sway of ±2 mm or so. Finally the difficulty of all subjects in either the seated or standing condition to detect a 4 mm move *vis a vis* the 1 and 16 mm ones (c.f., Figs. 1A,D) might also be hinting at a putative crossover near that region.

For our standing subjects, the somatosensory system (including tactile and proprioceptive feedback from natural resting sway) must have contributed significantly to the negative trading relationship between acceleration threshold and move displacement (or time), since simple vestibular input cannot account for that trade. For threshold 16mm anterior moves, a standing subject often had his/her AP Center of Pressure move 4 to 16 mm or so posteriorly after the move began, with concomitant early Tibealis Anterior EMG activation [11]. The increase in muscle tension and/or the rearward shift of the pressure profile under the soles of the feet [12] could have served as the basis for detection.

All the tests shown here were done with subjects blindfolded. We are now applying other test protocols in our lab with subjects standing or seated without being blindfolded, either being translated or viewing a translating visual scene, in order to study the contribution of the visual system to the threshold movement detection [13]. These are helping us further refine the contributions of the various sensory systems to the detection of short translational perturbations.

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