EFFECT OF SENSORY AUGMENTATION VIA SKIN STRETCH FEEDBACK ON QUIET STANDING BALANCE

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INTRODUCTION

Postural control and balance are two important factors to humans in performing activities of daily living (ADL). In the past two decades, studies [1] have shown that light touch (contact force less than 1N) of fingers on fixed surfaces can reduce postural sway during quiet standing and walking for people with or without dysfunction of sensory systems. With the help of additional sensory information from biofeedback, individuals with neurological impairments may improve their balance in ADL, which eventually can lead to enhanced quality of life. Recently, a portable sensory augmentation device was developed [2]. However, the efficacy of the device is not studied yet.

In this study, we examined whether augmented sensation at the fingertip via a newly developed portable sensory augmentation device (SAD) can modulate quiet standing postural sway. A closed-loop control strategy was implemented in this system for postural control. Furthermore, it is not known if the effect of sensory augmentation in balance enhancement depends on the availability of sensory modality. The objective of this study is to examine the effect of augmented sensation at the fingertip due to SAD on quiet standing balance of healthy young adults for various sensory modalities. It is hypothesized that augmented sensation enhances quiet standing balance more effectively when more sensory modalities are removed.

METHODS

Fifteen healthy young adults (four females and eleven males; mean age ± s.d.: 26.4 ± 5.6 years) with neither neurological nor musculoskeletal impairments participated in this study. Subjects were asked to stand quietly on a force plate (OR6, AMTI, Watertown, MA) under three conditions of availability of sensation: i) eyes-open (EO), ii) eyes-closed (EC) and iii) tilting head backwards with eyes closed (ECHU). Subjects put SAD on their right index finger (Fig. 1a). A belt enclosing an inertia measurement unit (IMU) (MPU-9150, InvenSense Inc., San Jose, CA) and an embedded control unit (myRIO, National Instruments, Austin, TX) was wrapped around waist of subjects (Fig. 1b). The details of SAD and control unit can be found at [2].

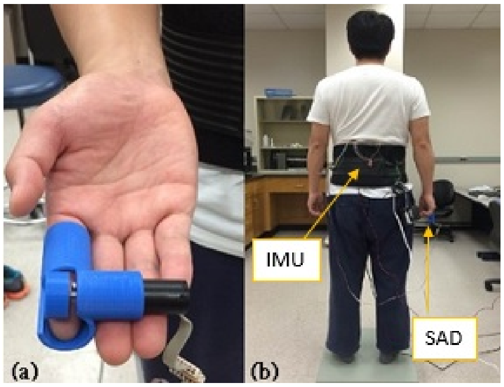

Figure 1: a) SAD, b) experiment setup

The experiments consisted of two parts: 1) practice session, and 2) main session. In the practice session, subjects were instructed to stand quietly on a force plate under three conditions of availability of sensation (EO, EC, and ECHU). The purpose of the session was to calibrate IMU by computing subject's reference angle while quietly standing, and to familiarize the subject with the testing environment. In the main session, subjects were asked to stand quietly on a force plate for 30s, with 10 repetitions for each sensory modality condition (EO, EC, ECHU) and SAD condition (on vs. off). Subjects were unaware of the function of SAD. Force plate data and pitch angle were sampled at 1kHz and 500Hz, respectively. Two-minute rests were given every five trials to avoid muscle fatigue.

SAD contactor was controlled by a position control where angular velocity of contactor was proportional to the angular deviation of pitch angle from the reference angle [2]. For example, when subject leaned forward (or backward) during quiet standing, the contactor rotated clockwise (or counterclockwise) so that the fingertip pad was stretched backward (or forward). This way, the subject was provided augmented sensory feedback of his/her postural sway.

From the force plate data, center of pressure (COP) was computed. From COP data, several traditional parameters such as maximum distance (*MaxDist*), range (*Range*), and mean frequency (*MeanFreq*) in anterior-posterior (AP), medial-lateral (ML) directions were computed [3].

To study the effect of availability of sensation and SAD on quiet standing balance, a two-way repeated measures ANOVA was performed. Level of significance was set to α=0.05 (SPSS, v21, Chicago, IL).

RESULTS AND DISCUSSION

Availability of sensory information significantly affected balance. *MaxDistAP*, *MaxDistML*, *RangeAP*, and *RangeML* indicated that postural sway was the smallest when all sensory information was available (EO), followed by when vision was lacking (EC), and followed by when both vision and vestibular information was deprived (ECHU) in both AP and ML direction (Table 1). These results agreed with previous studies that removing sensory information or challenging balance significantly increased postural sway [4].

Sensory augmentation due to SAD significantly affected balance. *MeanFreqAP* and *MeanFreqML* significantly decreased when sensory augmentation was provided (Table 1). *MeanFreq* is proportional to ratio of *Total Excursion* to *Mean Distance* or equivalently to ratio of *Mean Velocity* to *Mean Distance* [3]. This result suggests that sensory augmentation from SAD can reduce effective postural way that cannot be captured by the mean values of postural sway.

Our hypothesis that the effect of sensory augmentation due to SAD will be more prominent when less sensory modality was available was also supported. *MaxDistAP* and *RangeAP* had significant interaction effects between sensory availability and SAD. This interaction came from the fact that for EO/EC condition, SAD increased the mean values of *MaxDistAP* and *RangeAP* whereas for ECHU condition, SAD decreased the mean values of *MaxDistAP* and *RangeAP*.

One possible explanation is that sensory information during EO/EC conditions was enough to make stable balance whereas sensory information during ECHU condition was not enough to make stable balance so that additionally provided sensory augmentation could help improve balance.

Limitation of this study was as follows. Since SAD used position control and subject's reference angle kept changing over time during experiment, the quality of sensory feedback could be suboptimal. One possible solution would be applying velocity-based control where the reference angle does not affect the performance of SAD.

CONCLUSIONS AND FUTURE WORK

The efficacy of the developed sensory augmentation system via skin stretch feedback is evaluated. Our results indicate that the presence of additional sensory input helped maintaining balance when both visual and vestibular inputs were removed, substantiating our hypothesis. Future works include to 1) develop velocity-based controller (derivative control) and change the approach of obtaining the subject's reference angle, and 2) recruit groups of patients with impaired sensory systems to compare the quiet standing performance with normal subjects.

REFERENCES

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Table 1: Measures of postural sway. Value represents mean (standard deviation). Superscript denotes significant differences from indicated main effect condition ($p < .05$).

Parameters	Available Sensory Modality			Sensory Augmentation		Interaction
	EO (A)	EC (B)	ECHU (C)	With SAD (D)	No SAD (E)	*p*-value
MaxDistAP (m)	.012 (.001)^{BC}	.014 (.001)^{AC}	.017 (.001)^{AB}	.015 (.001)	.014 (.001)	**.013**
MaxDistML (m)	.006 (.0005)^{C}	.006 (.001)	.007 (.001)^{A}	.007 (.001)	.006 (.001)	.184
RangeAP (m)	.021 (.001)^{BC}	.024 (.001)^{AC}	.029 (.002)^{AB}	.026 (.002)	.024 (.001)	**.019**
RangeML (m)	.010 (.001)^{C}	.011 (.001)	.012 (.001)^{A}	.011 (.001)	.011 (.001)	.181
MeanFreqAP (Hz)	.360 (.024)^{B}	.395 (.022)^{A}	.391 (.024)	.370 (.025)^{E}	.395 (.021)^{D}	.421
MeanFreqML (Hz)	.461 (.027)	.441 (.028)	.430 (.028)	.421 (.029)^{E}	.466 (.025)^{D}	**.029**