VELOCITY-BASED SENSORY AUGMENTATION VIA FINGERTIP SKIN STRETCH ON QUIET STANDING

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INTRODUCTION

Posture control requires a highly coordinated central nervous system that integrates various sensory inputs into a singular percept of bodily information. Researchers have developed quantitative models to characterize sensorimotor integration in postural control. Modeling of multisensory fusion suggests that the sensory modality (e.g., vision, vestibular system, proprioception, and touch) can provide the dynamical information (position, velocity, and acceleration) of body sway [1]. With this theoretical framework, we have developed a sensory augmentation device (SAD) [2] that uses a skin stretch feedback to study postural sway behaviors under different sensory modality conditions. Our preliminary results [2] showed that augmented sensation via skin stretch feedback could help subjects correct their postures, especially as the level of deficiency of sensory feedback increased. This is also likely that the missing sensory information was compensated by additional dynamical information (i.e., position of COM). While Jeka et al. [1] reported that velocity information is the most accurate form of sensory information used to stabilize quiet standing posture compared to position and acceleration. In the current study, we have implemented a new control strategy for SAD using velocity-based sensory augmentation. The objective of this study is to examine whether skin stretch feedback based on time-derivative information of postural sway can enhance the postural sway for the healthy young adults with simulated sensory deficits.

METHODS

Fifteen healthy young adults with neither neurological nor musculoskeletal impairments participated in this study (3 females and 12 males; mean age ± s.d.: 25.6 ± 3.33 years old). All subjects were given the instructions of the experimental procedure, but they were not informed of the function of SAD. The written consent approved by the Texas A&M University Institutional Review Board was obtained from all subjects before each experiment.

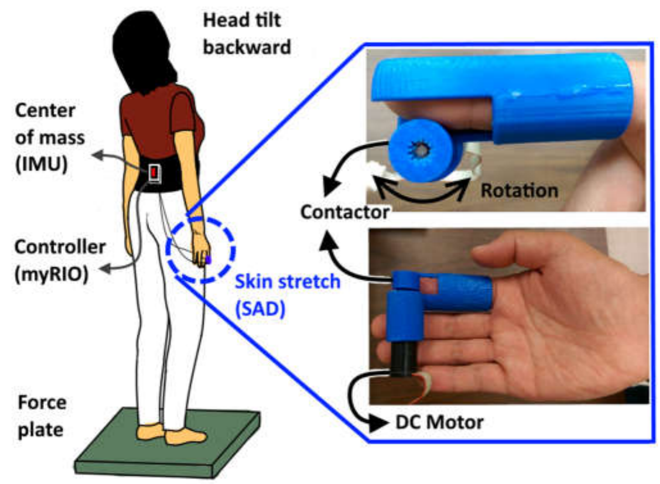

Figure 1: Experiment setup and SAD

Subjects were asked to perform quiet standing in normal bipedal stance on a force platform (OR6, AMTI, Watertown, MA). Center of pressure (COP) was computed in both anterior-posterior (AP) and medio-lateral (ML) direction. Subjects wore the SAD on their right index fingers which induced the light skin stretch at the fingertip pad through the shearing operated by a DC motor (1524T009SR, Faulhaber, Germany) (Fig. 1). An inertia measurement unit (IMU) (MPU-9150, InvenSense Inc., San Jose, CA) was attached to the back of waistline of each subject to measure the approximate location of the COM in AP direction. In our previous study [2], a position-based PID controller was implemented where the angular velocity of the contactor was set to be proportional to the deviation of COM position from the reference position. In the current study, we have developed another controller that is based on the time-derivative information (i.e., velocity) of COM. Namely, when a subject leans forward (or backward) and stays still, the contactor will stop and hence there will be no skin stretch applied on the fingertip pad.

To simulate the sensory deficit condition (vision and vestibular inputs), all subjects were asked to tilt their heads backward and close their eyes while standing on a force platform (Fig. 1). For head-extension posture, the vestibular organ is elevated relatively to its normal position, which puts the utricle otoliths into wrong position and consequently causes postural imbalance [3]. Two sensory augmentation conditions (with (SAD ON) and without (SAD OFF) skin stretch) were assigned with ten repetitions each in random order. For each trial, subjects stood on a force platform for 30 s. COP and pitch angle data were collected at a sampling rate of 1 kHz and 500 Hz, respectively.

The stochastic structure of postural sway was analyzed using a reduced-order finite Markov-chain model [4]. The location of the COP can be categorized as different states emanating from the centroid. It has been shown that the distribution of COP over the state space converges to a unique steady state distribution π, known as *invariant density* [4]. Therefore, by understanding the *invariant density*, we can observe the long-term postural sway behavior. Five parameters were used to characterize the *invariant density* to better understand the system dynamics. This technique is called Invariant Density Analysis (IDA) [4]. In this study, we examined five IDA parameters: *Ppeak, MeanDist, D95, EV2*, and *Entropy*. *Ppeak* is the largest probability of π. *MeanDist* is the average location of the COP. *D95* is the largest state at which there is a 95% probability of containing the COP. *EV2* is the 2nd largest eigenvalue of the transition matrix and describes the convergence rate of the system to the invariant density. *Entropy* is the measure of randomness. Traditional COP measures, *Range* and root mean square (*RMS)* of COP were also examined to provide statistical description. We report only the results in the radial direction, which is meaningful. One-way repeated measures ANOVA was performed. Level of significance was set to p=0.05 (SPSS, v21, Chicago, IL).

RESULTS AND DISCUSSION

Significant differences in COP measures were seen between the two sensory augmentation conditions (SAD ON and OFF) (Table 1). For traditional measures, *Range* and *RMS* significantly decreased when skin stretch feedback (SAD) was applied. This indicates that skin stretch feedback based on velocity strategy could reduce the postural sway. For IDA measures, *Entropy* significantly decreased when skin stretch feedback was applied. Even though no significant differences were found for other IDA measures, *D95* tended to decrease (p=0.062) when SAD was on. Small value of *D95* indicates that COP stayed closer to the centroid. A smaller *Entropy* with SAD ON implies more active sensorimotor integration in the central nervous system and thus more active control to keep the COP close to the center [4]. This result suggests that when the additional skin stretch based on velocity-related COM information was applied, subjects could more actively control their posture towards a relative equilibrium position.

Table 1: Measures of postural sway. Value represents mean ± standard deviation (n=15).

	SAD OFF	SAD ON	*p*-value
Traditional measures			
Range	16.79±6.46	15.61±5.70	**0.008**
RMS	6.308±2.18	5.86±1.85	**0.045**
IDA measures			
Ppeak	0.034±0.01	0.035±0.01	0.455
MeanDist	5.350±1.69	5.001±1.45	0.109
D95	12.36±4.75	11.24±3.68	0.062
EV2	0.998±0.00	0.998±0.00	0.189
Entropy	5.871±0.44	5.762±0.44	**0.032**

CONCLUSIONS

In this study, we demonstrated that skin stretch feedback based on velocity-related COM information has successfully compensated the missing information and stabilized the inherently unstable posture, when two sensory systems were perturbed in healthy young adults. Future work includes recruiting healthy elderly adults to examine the efficacy of SAD.

REFERENCES

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