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.
- 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].
- Velocity information may be a more accurate form of information acquired by sensory systems when compared to position and acceleration information [1,2].
- By mimicking the shear force that subjects might experience when touching on a fixed surface, we have developed a portable sensory augmentation system [3] for standing balance rehabilitation using skin stretch feedback.
- In this study, we considered the body velocity information of the body sway as the reference to correct postural sway while standing.

Objectives

- To examine the effectiveness of the velocity-based sensory augmentation via skin stretch feedback on quiet standing.
- To understand how skin stretch feedback is being interpreted to help maintain standing balance and to examine whether the body sway velocity is a more naturally inherited form for subjects wearing the portable sensory augmentation device to perceive compared to sway position.

Experiment Protocol

Subjects

- Fifteen healthy young adults (3 females and 12 males; mean age ± s.d.: 25.6 ± 3.3 years old) with neither neurological nor musculoskeletal impairments participated in this study.
- All subjects were given the instructions of the experimental procedure and the consent form before the experiment. No other instructions were given to subjects, e.g., try to make the contactor stop rotating.

Protocol

- 30-second quiet standing on a force plate (OR6, AMTI, Watertown, MA) with simulated sensory deficits and two sensory augmentation conditions was performed.

Simulated Sensory Deficit

Eyes closed and
head tilt backward at least 45°

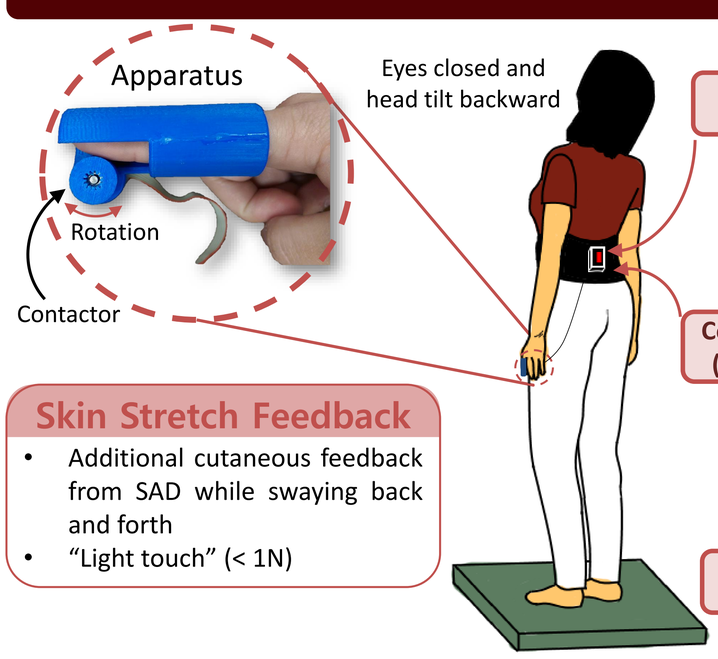
+

Sensory Augmentation Conditions

1. SAD is turned on
2. SAD is turned off

- Subjects wore the SAD on their index finger and put on the waist belt and an overhead safety harness for the protection against unexpected falls.
- In the experiment, each condition was repeated 10 times to minimize random effects and the order of the total 20 trials was fully randomized. Break was provided every five trials to avoid muscle fatigue.

Sensory Augmentation System



Skin Stretch Feedback

- Additional cutaneous feedback from SAD while swaying back and forth
- "Light touch" (< 1N)

IMU

- Placed at estimated center of mass location.
- Measures the sway angle in subject's anterior-posterior (AP) direction (e.g., lean angle).

Controller (myRIO)

Control Strategy

- Velocity-based control was used.
- Desired angular velocity for the contactor was defined to be proportional to the difference of the angular derivation of pitch angle.
- When the subject sways more quickly, contactor rotates faster; when staying still, the contactor stops.

Force Plate

- Measures the center of pressure (COP) displacement.
- Data were processed offline using MATLAB.

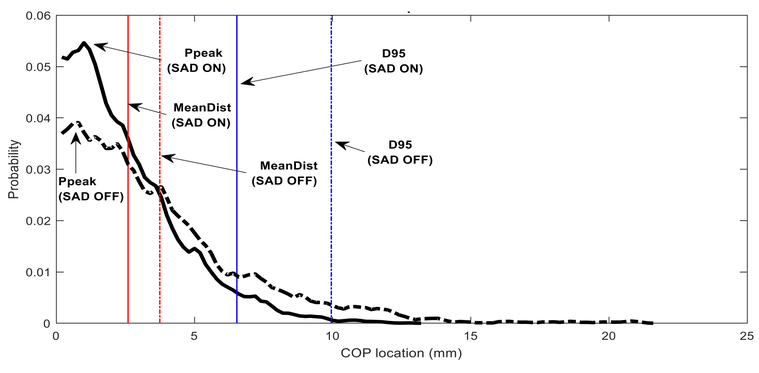
Postural Sway Analyses

- Traditional COP measures, maximum distance (MaxDist), *Range* and *root mean square (RMS)* of COP were examined to provide statistical description [4].
- The stochastic structure of postural sway was analyzed using a reduced-order finite Markov-chain model, so-called *Invariant Density Analysis* (IDA) [5]. We examined five IDA parameters: *Ppeak, MeanDist, D95, EV2, and Entropy.*
- Postural sway measures were computed in the radial (Rad) direction.
- One-way repeated measures ANOVA was performed. Level of significance was set to p =0.05.

Results

- Significant differences in COP measures were seen between the two sensory augmentation conditions (SAD ON and OFF) (Table 1).
- For traditional measures, *MaxDist, Range* and *RMS* significantly decreased when SAD was ON.
- For IDA measures, *Entropy* significantly decreased when SAD was ON.
- Even though no significant differences were found for other IDA measures, *D95* tended to decrease (p=0.06) when SAD was on.

Fig. 1. Invariant densities plot of subject #10



	SAD OFF	SAD ON	Change rate	p-value
Traditional measures				
MaxDist (mm)	17 ± 6.65	15.77 ± 5.74	-7.2 %	**0.01**
Range (mm)	16.79 ± 6.46	15.61 ± 5.70	-7.1 %	**0.008**
RMS (mm)	6.308 ± 2.18	5.86 ± 1.85	-7 %	**0.045**
IDA measures				
Ppeak	0.034 ± 0.01	0.035 ± 0.01	+2.9 %	0.455
MeanDist (mm)	5.350 ± 1.69	5.001 ± 1.45	-6.5 %	0.109
D95 (mm)	12.36 ± 4.75	11.24 ± 3.68	-9.1 %	0.062
EV2	0.998 ± 0.00	0.998 ± 0.00	0 %	0.189
Entropy	5.871 ± 0.44	5.762 ± 0.44	-1.9 %	**0.032**

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

Conclusions

- Skin stretch feedback based on COM sway velocity could reduce postural sway.
- The additional fingertip cutaneous sensation helped the users' sensorimotor integration for standing balance.
- Compared to our previous study [3], velocity-based skin stretch feedback enhanced postural sway more robustly than position-based skin stretch feedback.
- From IDA, it shows that COP stayed closer to the centroid; a smaller Entropy with SAD ON implies a more deterministic system that one can more actively controls and keeps their COP close to a relative equilibrium position
- Some improvements for the next generation device are ongoing including subject-specific apparatus design and different wearable location (e.g., wrist, forearm).
- Elderly people or other neurologically-impaired patients will be recruited for the future work.

References

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