A PILOT STUDY ASSESSING EFFECTS OF TAPING THE ANKLE TENDONS ON POSTURAL CONTROL UNDER UNPREDICTABLE PERTURBATION

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Unpredictable external perturbation significantly degrades balance and increases the risk of falls, so methods to improve postural control under such perturbation are expected to be beneficial. Considering the important role of somatosensory feedback from ankle tendons in balance regulation, we proposed that applying adhesive elastic tapes to the ankle tendons may affect the postural control. In this initial pilot study, we recruited four healthy young adults and instructed them to balance under forward and backward perturbation which was applied at unpredictable timing by an electrically controlled actuator. The task was performed with and without the application of tapes. We found that cutaneous stimulation to the ankle tendons significantly reduced the peak displacement of the center of pressure ($p = 0.008$), and changed activations of multiple muscles (gastrocnemius medialis: $p = 0.041$, biceps femoris: $p = 0.023$, and erector spinae: $p = 0.035$) under forward direction perturbation. In contrast, no significant difference was observed under backward direction perturbation. Our findings suggest that cutaneous stimulation by applying adhesive elastic tapes can affect the postural control under unpredictable external perturbation, but its effect may depend on the direction of the perturbation.

KEYWORDS: cutaneous stimulation, external perturbation, postural control.

INTRODUCTION: Although healthy humans can easily maintain intended posture in usual and predictable circumstances, unpredictable external perturbations frequently jeopardise the necessary postural stability (Santos et al., 2010; Aruin et al., 2015). To prevent falls, compensatory muscle activations and joint movements are generated within a short time frame (under 350 milliseconds) after the onset of perturbation, which is termed as the compensatory postural adjustment (CPA) phase. Previous studies have shown that unpredictable perturbation during a quiet standing can bring the center of pressure (COP) towards the margin of the base of support (Santos et al. 2010). In addition, perturbation-induced muscle latencies were delayed, and muscle activations exponentially increased for the lower limb and trunk muscles as the postural control strategy shifted from ankle to hip strategy. These findings clarify that unpredictable perturbation causes larger balance deterioration and increases the demand for the muscular efforts.

Both feedforward and feedback systems work synergistically to compensate for the balance deterioration caused by external perturbations (Massion, 1998). Under unpredictable perturbations, the role of somatosensory feedback system becomes especially essential in compensating for balance deterioration (Paterka, 2002). Additional stimulation to the distal joints might mitigate balance deterioration because sensory feedback from these joints plays a crucial role in balancing. Tendons and skin over the tendons particularly contain a large number of mechanoreceptors, so adding tactile stimulation to tendons can be a feasible way to modulate postural control (Wierzbicka et al., 1998). A simple, passive, and non-invasive method to enhance sensory feedback from the ankle joints is adding cutaneous stimulation by applying adhesive elastic tapes to the skin over the tendons. Previous studies have shown that the application of these tapes to the ankle tendons enhances proprioception and improves balance while maintaining upright posture (Simoneau et al., 1997; Thedon et al., 2011).

In this initial pilot study, we aim to evaluate the effect of cutaneous stimulation via elastic adhesive tapes to the ankle tendons on postural compensation after unpredictable external perturbation. We hypothesize that the application of cutaneous stimulation to the ankle tendons decreases the COP displacement, and changes the activation levels and latencies of the lower limb and trunk muscles in response to unpredictable external perturbations.

METHODS: We recruited four healthy young adults (two males and two females; age: 24.25± 2.06 years; height: 1.73 ± 0.12 m; weight: 65.65 ± 12.71 kg) without neuromuscular and orthopedic injuries. All aspects of this study were approved by the Institutional Review Board of Seoul National University (IRB No. 2004/001-016), and consented by the participants.
We used a cable-driven variable resistance machine (CrossMAST, MASTS Inc.; resistance range: 20~450 N; cable length: 5 m; maximum pull speed: 18 m/s) to apply quantitatively controlled external mechanical perturbation. The speed of cable movement was recorded at 100 Hz. We recorded the COP at a sampling frequency of 1000 Hz using a force platform (Bertec Inc., USA). Non-invasive surface electromyography (EMG) sensors (Delsys Inc., USA) were used to record the muscle activations of 12 muscles at a sampling frequency of 2000 Hz: the gastrocnemius medialis (GM), tibialis anterior (TA), biceps femoris (BF), rectus femoris (RF), erector spinae (ES), and rectus abdominis (RA) of both legs. We synchronized the initiation of data acquisition of the three systems using sync boxes. We provided cutaneous stimulation to the Achilles and tibialis anterior tendons using 5 cm wide adhesive elastic tape (NIPPON Sigmax Co., Ltd., Japan).
During the experiment, we provided participants with a vest equipped with rings at the front and back, where the cables were attached to apply controlled tension. We placed the EMG sensors and asked participants to stand on the force platform with their eyes closed and feet shoulder-width apart. We also equipped participants with earbuds to cancel out the noise that occurred when the cable was pulled. The cable connected to the vest was initially slack, but the cable pulled participants towards the resistance machine as soon as the tension in the form of a rectangular pulse was applied. Consulting the methods of previous studies, we set the perturbation duration and amplitudes as 500 ms (He & Tian, 1996) and 7% of the participant's body weight (Verniba & Gage, 2019), respectively. The total time of each trial was 20 seconds, and the onset time of the perturbation was randomized between 5 and 15 seconds. Participants performed five trials for each of four experimental conditions, forward and backward direction perturbation with the adhesive tape (Tape) and without it (No tape). We provided 20 seconds of rest between trials. We provided participants with 3 practice trials each for forward and backward direction perturbations. The taping sequence was pseudo-randomized, and the perturbation direction was randomized within each taping condition. The tape was applied between the insertion points of the tibialis anterior and Achilles tendons while participants maintained the angle between shank and foot as 90 degrees.
We detected the onset time of the perturbation (T0) as the time point when the cable speed exceeds 5% of its maximum (Aruin et al., 2015). We then extracted the dataset from two phases: 1) baseline (between 500 ms and 450 ms before T0) and 2) CPA (between 50 ms and 350 ms after T0). The raw COP coordinates were filtered using a zero-lag fourth-order low pass Butterworth filter with a cut-off frequency of 20 Hz. We then calculated the peak COP displacement (COP_{disp}) as the difference between the maximum values of filtered COP during CPA and the average values of filtered COP during the baseline. To quantify the muscle activations, we filtered the raw EMG signals using a zero-lag fourth-order band-pass filter with a cut-off frequency between 20 and 350 Hz, which was further smoothened using a moving average filter with a time window of 1% of the length of the EMG signal for each trial. We calculated the difference between the integrated EMG (IEMG) during CPA and baseline. We then divided the difference by the maximum IEMG, which is the highest value among all of the integrated values over 10% length of the dataset. We defined this ratio as normalized integrated EMG (NormIEMG). We additionally calculated the muscle latency as the first time point when the smoothened EMG amplitude was larger or smaller than mean ± three standard deviations of the EMG amplitude within the baseline phase for more than 50 ms (Aruin et al., 2015). The NormIEMG and muscle latency values were calculated separately for each muscle and were averaged across the two limbs. Paired t-test was used to determine any significant difference in the peak COP_{disp}, NormIEMG, and muscle latency values between No tape and

Tape conditions, separately for forward and backward perturbations. We tested the assumption of normality using Shapiro-Wilk test separately for each experimental condition, and found that all the values were normally distributed. The level of statistical significance was set as $p < 0.05$.

RESULTS: Figure 1 shows the mean and standard error (SE) of the peak COP_{disp} and NormIEMG values of lower limb and trunk muscles for four participants under No tape and Tape conditions for the forward and backward direction perturbations. The peak COP_{disp} values under Tape condition were significantly lower than those under No tape for the forward direction perturbation; $t(3) = 6.351$, $p = 0.008$, $d = 0.351$, whereas no significant difference was found for backward direction perturbation. For forward direction perturbation, the NormIEMG values of the GM muscle under Tape condition were significantly higher than those under No tape condition; $t(3) = 3.698$, $p = 0.041$, $d = 0.396$. In contrast, NormIEMG values of the BF and ES muscles under Tape condition were significantly lower than those under No tape condition; BF: $t(3) = 4.316$, $p = 0.023$, $d = 0.549$ and ES: $t(3) = 3.752$, $p = 0.035$, $d = 0.466$. For backward direction perturbation, no statistically significant difference in the NormIEMG values between No tape and Tape conditions was observed for any of the muscles. For perturbations in both directions, muscle latency values were not significantly different between taping conditions.

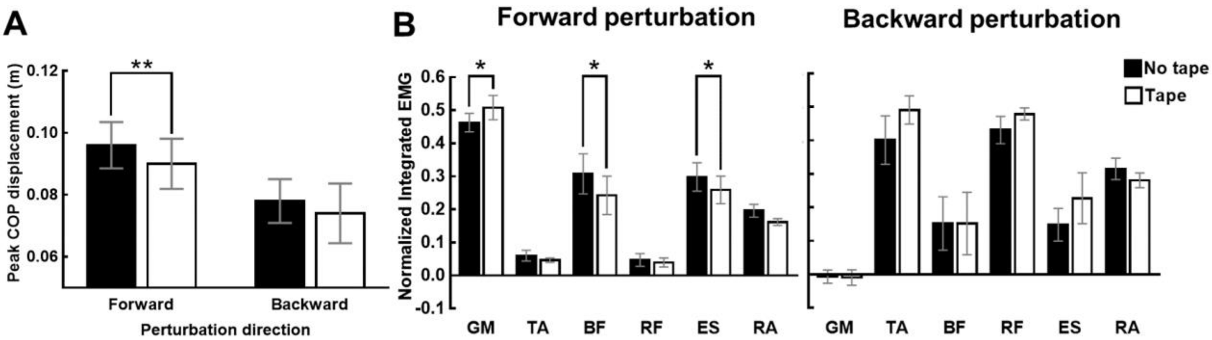

Figure 1: Effects of cutaneous stimulation via adhesive elastic tapes applied over the shank tendons on (A) peak COP displacement (COP_{disp}) and (B) normalized integrated EMG (NormIEMG) of 6 muscles. **: p<0.01 and *: p<0.05 denote statistical significance.

DISCUSSION: In this study, we investigated the effect of tape-induced cutaneous stimulation to the ankle tendons on postural control under unpredictable perturbations. We showed that applying adhesive tapes to the ankle tendons decreased peak COP displacement and changed the activation levels of some muscles only under forward direction perturbations. These results suggest that tapes can be useful for mitigating balance deterioration under unpredictable perturbation in the forward direction.

Peak COP displacement is the primary indicator to evaluate the postural compensation (Santos et al., 2010; Aruin et al., 2015); an increase in the peak COP displacement indicates that the body's point of force application is getting closer to the margins of the base of support, increasing the risk of fall. Additional somatosensory feedback through cutaneous stimulation is known to enhance proprioception of the ankle joint, which is essential for compensating for balance deterioration (Simoneau et al., 1997; Thedon et al., 2011). We found that application of the adhesive tape decreased the peak COP displacement under forward direction perturbation and changed the muscle activation levels. The observed change in muscle activation levels indicates that the tapes allowed the participants to rely more on distal muscles and less on proximal muscles. These observations suggest that the shift from ankle to hip strategy and the resulting increase in the demand for the muscular efforts can be delayed or reserved by virtue of the tape-induced cutaneous stimulation.

In contrast, under backward direction perturbation, we found no significant effect of the tapes on both the peak COP displacement and muscle activation level; the efficacy of the tape-induced stimulation clearly depended on the direction of the perturbation. The less noticeable effect of the induced cutaneous stimulation on the performance and strategy under posterior perturbation may be due to the difficulty of the task. The margin of the base of support during

posterior body deviation in a standing position is significantly smaller compared to anterior deviation (Duarte & Zatsiorsky, 2002). Therefore, balancing under unpredictable backward perturbation demands higher efforts and readily requires the most effective and safe strategy to keep COP within the small margin of the base of support.
In this initial pilot study, the sample size ranged from 0.351 to 0.549. These small to medium effect sizes might limit the generalizability of the results. Hence, it is necessary to further confirm the results of our study with a larger sample.

CONCLUSION: We are vulnerable to balance deterioration and falls due to unpredictable external perturbations. In this initial pilot study, we suggest a simple, quick but effective method for enhancing postural compensation. Applying commercially-available elastic adhesive tapes to ankle tendons could provide additional somatosensory feedback and mitigate the balance deterioration caused by unpredictable anterior perturbations for young and healthy adults. Further studies may show the efficacy of similar simple intervention in patients suffering from somatosensory abnormalities such as peripheral neuropathy and the elderly who have significantly impaired postural compensation and the higher risk of falling (Meyer et al., 2004).

REFERENCES

Aruin, A. S., Kanekar, N., & Lee, Y. J. (2015). Anticipatory and compensatory postural adjustments in individuals with multiple sclerosis in response to external perturbations. *Neuroscience Letters*, *591*, 182-186.
Duarte, M., & Zatsiorsky, V. M. (2002). Effects of body lean and visual information on the equilibrium maintenance during stance. *Experimental Brain Research*, *146*(1), 60-69.
He, J., & Tian, C. X. (1996). Adaptive postural control for a repeated perturbation. In *Proceedings of 18th Annual International Conference of the IEEE Engineering in Medicine and Biology Society* (Vol. 5, pp. 2215-2216). IEEE.
Massion, J. (1998). Postural control systems in developmental perspective. *Neuroscience and Biobehavioral Reviews*, *22*(4), 465-472.
Meyer, P. F., Oddsson, L. I., & De Luca, C. J. (2004). Reduced plantar sensitivity alters postural responses to lateral perturbations of balance. *Experimental Brain Research*, 157(4), 526-536.
Peterka, R. J. (2002). Sensorimotor integration in human postural control. *Journal of Neurophysiology*, *88*(3), 1097-1118.
Santos, M. J., Kanekar, N., & Aruin, A. S. (2010). The role of anticipatory postural adjustments in compensatory control of posture: 1. Electromyographic analysis. *Journal of Electromyography and Kinesiology,* 20(3), 388-397.
Simoneau, G. G., Degner, R. M., Kramper, C. A., & Kittleson, K. H. (1997). Changes in ankle joint proprioception resulting from strips of athletic tape applied over the skin. *Journal of Athletic Training*, *32*(2), 141.
Thedon, T., Mandrick, K., Foissac, M., Mottet, D., & Perrey, S. (2011). Degraded postural performance after muscle fatigue can be compensated by skin stimulation. *Gait and Posture*, *33*(4), 686-689.
Verniba, D., & Gage, W. H. (2019). Stepping threshold with platform-translation and shoulder-pull postural perturbation methods. *Journal of Biomechanics*, *94*, 224-229.
Wierzbicka, M. M., Gilhodes, J. C., & Roll, J. P. (1998). Vibration-induced postural posteffects. *Journal of Neurophysiology*, *79*(1), 143-150.

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