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Effectiveness of Bracing and Taping, and the Influence of Light Finger Touch, During Unexpected Ankle Inversion Perturbations

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Abstract

Ankles are the most frequent site of musculoskeletal injury and a major cause for lost time in sports. Taping and bracing are commonly used to support unstable ankle joints. The purpose of this project was to evaluate whether taping or bracing effectively reduce ankle motion, or alter the timing or amplitude of muscle activation, during unexpected perturbations. 14 male subjects stood on their right foot on an inversion motion platform and underwent a sudden inversion. Half of the subjects had finger contact with a stationary touch platform and the other half was without finger touch contact. All subjects performed taped, braced and control trials. Surface EMG was recorded from the right soleus, peroneus longus, medial gastrocnemius, tibialis anterior, vastus medialis, vastus lateralis, gluteus medius and biceps femoris muscles, and an electrogoniometer measured ankle joint motion. Peak activations following the perturbation were quantified, and timing focused on the peroneus longus. There were no statistically significant differences in peroneal onset between touch and no touch, or between the different ankle support conditions. The peak angles in the braced and taped conditions were both significantly less than the control condition (40% change). There were no significant differences in peak muscle activation between the taped, braced and control conditions. Finger touch had significantly less peak muscle activation for soleus, tibialis anterior, vastus medialis and vastus lateralis (12-25% reduction). In conclusion, both taping and bracing limited ankle inversion during an unexpected ankle perturbation, and light finger touch significantly decreased muscle activation in four of the muscles related to standing balance.

Keywords

Inversion, Electromyography, Joint instability, Functional ankle instability, Balance control

Abbreviations

EMG: Electromyography, MVIC: Maximum Voluntary Isometric Contractions

Introduction

Ankle sprains are one of the most frequent musculoskeletal injuries experienced by athletes and are a major cause for missed time in sport [1]. Lateral ankle sprains occur frequently due to the greater range of motion associated with inversion compared to eversion, and decreased stiffness, a measure often related to stability [2]. Lateral ankle injuries have a higher incidence in indoor/court sports, such as basketball or volleyball; a recent meta-analysis reported that the incidence rate was 7/1,000 cumulative exposures, or 1.37/1,000 athlete exposures corresponding to 4.9/1,000 hours of athlete exposure [1].

Many preventative techniques have been developed due to the high frequency of injuries in sport. Non-elastic tape and braces are common methods to prevent further injury and to provide additional stability to the ankle joint during competition [3]. Taping provides external support by holding the foot in a neutral position thereby reducing ligamentous stress from inversion and eversion movements occurring about the subtalar axis [4]. When correctly applied, tape acts as an external ligament that can restrict extreme joint motion [5,6], and reduce the likelihood of lateral ankle sprains. For example, the effectiveness of taping was studied over two successive seasons on 2563 basketball players with a history of lateral ankle sprains [7]; the incidence of sprains in the taped players was 6.5/1000 compared to 30.4/1000 for non-taped players. Ankle braces also reduce the risk of acute ankle injury. For example, the effectiveness of ankle braces was studied in 1601 basketball players over a two-year period [8]; individuals in the control group were three times more likely to experience an ankle injury than the braced group.

Hertel describes that chronic ankle instability can be caused by mechanical insufficiency (caused by pathologic laxity and degenerative changes) or functional insufficiency (a result of deficits in proprioception and neuromuscular control) [9]. Therefore, in order to prevent chronic ankle instability, the external supports must mitigate these factors.

It has been proposed that pre-contracted peroneal muscles are the main naturally occurring support system to prevent ankle inversion during landings from a jump in healthy subjects [10]. Literature reviews have reported that both taping and bracing effectively limit ankle motion during exercise in order to prevent injury [3]. However, braces offer some advantages including that they can be self-administered without needing the expertise of qualified personnel, they are convenient to apply and remove, and are reusable, readjustable, and washable [3]. They also provide mechanical stabilization and proprioceptive stimulation [11-13].

Several studies that used a trapdoor mechanism to simulate an inversion injury discovered that using athletic tape shortened

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the peroneus muscle reaction time to a sudden perturbation in participants with unstable ankles [14-16]. In contrast, one study measured delayed peroneal response times in athletes with both stable and unstable ankles for taped and braced conditions compared to the control condition [17]. In terms of amplitude of muscle activation, one study demonstrated significantly larger EMG values for peroneus longus muscle for the taped condition compared to control [16]; they attributed this to greater proprioception received via cutaneous cues from the tape.

A number of studies have used haptic cues from fingertip contact to evaluate regulation of balance [18-22]. Light touch with the index finger to a touch platform significantly reduced postural sway compared with no touch conditions [18,22]; these effects are thought to be mediated through increased proprioception as the forces from touch contact were not large enough to correct loss of balance [22].

The primary purpose of this study was to determine whether taping and bracing effectively reduced ankle motion during perturbations in subjects with no injury history. The secondary goals of this study were to evaluate whether taping and bracing altered the amplitude and onset of muscle activation, as well as whether the effect of light finger touch on a fixed surface reduced muscle activation in muscles responsible for posture stability. We hypothesize that the peroneal muscle activation will be delayed in both the taped and braced conditions compared to control, and that mean muscle activation amplitude for peroneus longus will be highest in the taped condition followed by braced and control, respectively, due to the cutaneous cues provided from both stabilization methods. Furthermore, we hypothesize that use of the touch platform will reduce mean muscle activation amplitude for all muscles involved in regulating balance.

Methods

Subjects

Fourteen male subjects (mean age=19.21 ± 1.37 years) participated in the study. All subjects were moderately active and presented with no current or past ankle or lower leg injuries. Subjects were tested for leg dominance based on a published protocol [23]. The University of Western Ontario Human Subjects Research Ethics Board approved the study protocol and all subjects provided written consent prior to participating.

Study protocol

All subjects stood on their right foot in the center of the inversion motion platform (R3000, Mikrolar Inc., Hampton, NH, USA); the surface of the platform was located one meter above the ground and had a diameter of one meter. The platform underwent a sudden 7.5 degree tilt, at a rate of 40 degrees/second, forcing the ankle into inversion; the tilt followed a random delay of 1-5 seconds so that the participants could not anticipate the timing of the perturbation. All subjects were secured with a safety harness that looped around their legs and pelvis. The harness was anchored to the ceiling, and would arrest their fall if they lost their balance. All fourteen subjects performed taped, braced and control trials, where the order of conditions was blocked and the order of presentation of the blocks was randomized between subjects. The first seven subjects performed the trials without the aid of a touch platform while the final seven subjects performed the trials with a touch platform. The design and positioning of the touch platform was modeled after the platform used by other researchers [20]. Subjects placed two fingers in contact with the touch platform that was located at waist height at their right side. A TriLok ankle brace (Bioskin 53603, Cropper Medical Inc., Ashland, OR, USA) was used for the braced condition. Standard athletic non-elastic white tape was applied in the closed basket configuration, by a registered physiotherapist, for the taped condition.

Instrumentation

Electromyographic activity for eight muscles in the right lower limb was measured using wireless EMG sensors (Trigno, Delsys Inc., Boston, MA, USA). Soleus, peroneus longus, medial gastrocnemius and tibialis anterior were investigated as they play a role in the medio-lateral ankle stability during stance. Vastus medialis, vastus lateralis, gluteus medius and biceps femoris were also investigated, as they play a role in weight bearing during single leg stance. The electrode sites were identified following SENIAM recommendations [24], and were wiped with alcohol swabs to reduce skin impedance and to ensure appropriate electrode adherence. The electrodes were aligned parallel to the muscle fibers and were secured to the skin via tape to prevent electrode movement. The end-blocks of an electrogoniometer (Model #SG150 Biometrics, Gwent, UK) were attached to the posterior aspect of the calf and the calcaneus using double-sided tape such that the flexible measuring element passed across the ankle joint complex. This enabled measurements of right ankle joint inversion/eversion rotation similarly to other researchers [6,25]. Previous research has shown that this method of attachment of the electrogoniometer is reliable [25], and that the flexible elements within these electrogoniometers render them insensitive to joint translations and the specific location of the joint axis of rotation [26]. The goniometer was integrated with the Trigno wireless system (Delsys Inc., Boston, MA, USA). In addition, a wireless accelerometer (Trigno sensor, Delsys Inc., Boston, MA, USA) was placed on the motion platform to determine motion onset. The EMG, electrogoniometer and accelerometer signals were sampled at 2000Hz and stored for subsequent analysis.

Maximum voluntary isometric contractions

Each subject performed maximum voluntary isometric contractions (MVICs) for each muscle of interest based on a published protocol [27] in order to reduce inter-individual variability [28]. Three four-second MVICs were recorded for each muscle with a two-minute break between each contraction, similarly to other researchers [29,30]. Each MVIC was specific to the muscle of interest, with the goal of isolating the specific muscular contraction. For soleus, the subjects attempted to plantarflex against manual resistance while seated with their knee at 90 degrees. For medial gastrocnemius, the subjects attempted to plantarflex against fixed resistance with their knee extended while lying prone. For peroneus longus, the subjects attempted to evert their ankle against manual resistance while laterally recumbent. For tibialis anterior, the subjects attempted to dorsiflex against manual resistance while standing. For gluteus medius, the subjects attempted to abduct their leg against manual resistance while laterally recumbent. For vastus medialis and lateralis, the subjects attempted to extend their knee against fixed resistance while seated with their knee at 90 degrees. For biceps femoris, the subjects attempted to flex their knee against fixed resistance while seated with their knee at 90 degrees. The subjects were instructed to exert maximal force against resistance and were given verbal encouragement to promote maximal effort.

Data analysis

Data processing was performed using custom programs written in LabVIEW (Version 2010, National Instruments, Austin, TX, USA). An automated method was used to identify the perturbation onset based on the signal from the accelerometer signal, and the onset of muscle activation from the raw EMG signals [31]. These onsets were manually confirmed based on a threshold method [32]. We were not able to reliably determine the onset for trials that had significant activation prior to the perturbation, and therefore we deemed these trials to be "unsuccessful". In contrast, trials with low levels of activation prior to the perturbation, and activation bursts after the perturbation, were deemed to be "successful". The proportion of successful trials was quantified to reflect the frequency of trials with clear responses to the perturbation. The muscle activation onsets were expressed with respect to the onset of the perturbation. For amplitude analysis, the EMG signals were rectified and then passed through a 2^{nd} order low pass Butterworth filter with a cutoff frequency of 3Hz [33]. The peak muscle activation was extracted from these traces and averaged across subjects. The electrogoniometer output was calibrated into degrees; standing was normalized to zero degrees, and the peak inversion angle from each trial was recorded.

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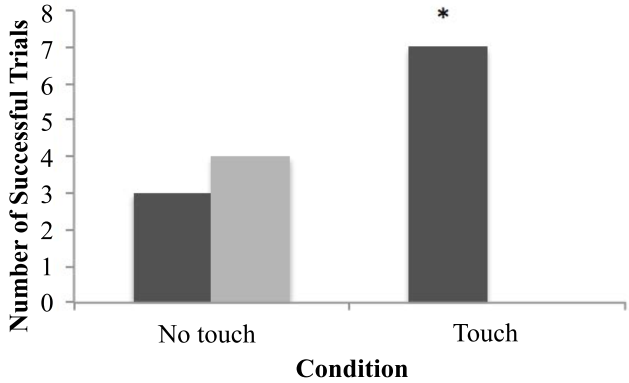

Figure 1: The number of successful trials in the touch and no touch conditions. Dark grey bars represent successful trials, and light grey bars represent unsuccessful trials. Statistically significant differences are indicated by*.

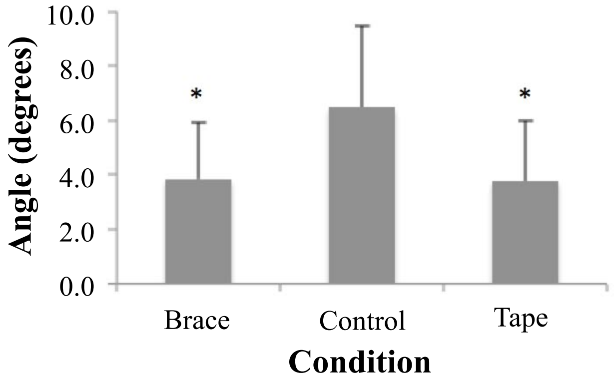

Figure 3: Differences in mean inversion angle among conditions. The * represent a statistical significant difference from control condition. The error bars represent one standard deviation.

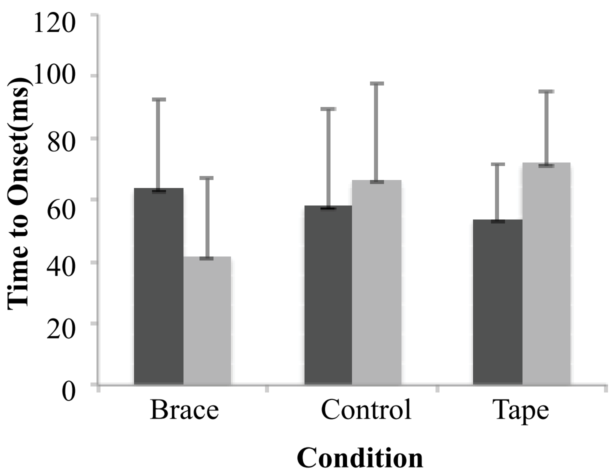

Figure 2: Mean peroneus longus onset. Dark grey bars represent the touch condition. Light grey bars represent the no-touch condition. Differences were not statistically significant. The error bars represent one standard deviation.

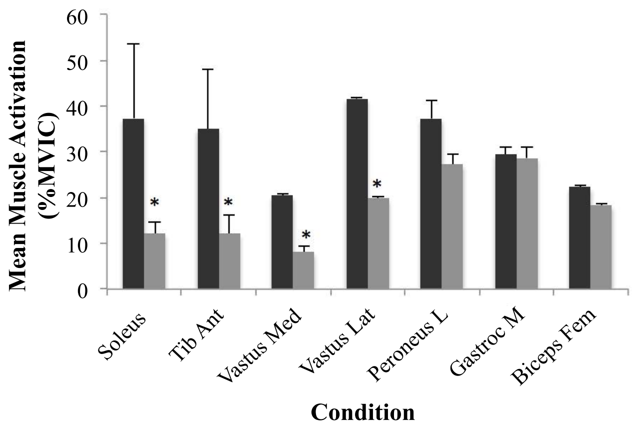

Figure 4: Peak muscle activation for each of the lower extremity muscles, averaged across subjects, with and without the touch platform. Dark grey bars represent the no-touch condition. Light grey bars represent the touch condition. The * represent statistically significant differences between the touch and no-touch conditions. The error bars represent one standard deviation.

Statistical analysis

A chi-squared test was used to determine if the proportion of successful trials with the touch platform was significantly different than without the touch platform. The statistical significance of differences in activation and latency for each muscle were evaluated using 2-way ANOVA tests with touch (touch and no-touch) and condition (taped, braced and control) factors. If statistically significant differences arose, then post-hoc tests were performed to identify the statistically significant comparisons. Statistical significance was set at the $p<0.05$ level.

Results

Only two of the fourteen subjects presented with left leg dominance. There was one left leg dominant participant in each group so they would not have had a disproportionate effect on the results. Given the small number of participants with left leg dominance, this parameter was not further analyzed, and the analysis considered the group as a whole.

The proportions of successful trials data are presented in Figure 1. The touch condition had a significantly greater proportion of successful trials compared to the no touch condition ($p = 0.035$).

Peroneal onset

The condition-by-group interaction for peroneus longus was not statistically significant ($p=0.072$), and neither were the differences in peroneal onset between the taped, braced and control conditions ($p=0.797$), nor the differences in peroneal onset between the touch and no touch conditions ($p=0.912$). However, we note that the condition-by-group interaction approached statistical significance; Figure 2 shows that the onset of the peroneus longus muscle was shorter in the no-touch condition than touch condition for individuals that were wearing the brace, but the large amount of variability reduced our power to detect this difference as statistically significant.

Inversion angle

The condition-by-group interaction for inversion angle was not statistically significant ($p=0.862$). The differences in the effect of touch and no touch for inversion angle were not statistically significant ($p=0.113$), but there were statistically significant differences between conditions ($p<0.0001$; Figure 3); post-hoc testing revealed that the peak inversion angle in the taped (3.8°; $p=0.046$) and braced (3.8°; $p=0.038$) conditions were both significantly less than the control (6.5°) conditions, but were not significantly different than each other ($p=0.871$).

Peak muscle activation

For the soleus, there was no significant condition-by-group interaction, and the effect of condition was not significant. There was significantly less muscle activation in the touch condition compared to the no-touch condition ($p=0.008$; Figure 4). The peroneus longus and medial gastrocnemius muscles both exhibited no statistically significant condition-by-group interaction, and no statistically significant differences in effect of touch or between conditions. No statistically significant condition-by-group interaction or statistically significant differences in the effect of condition were found for the tibialis anterior muscle; however, there was significantly less muscle

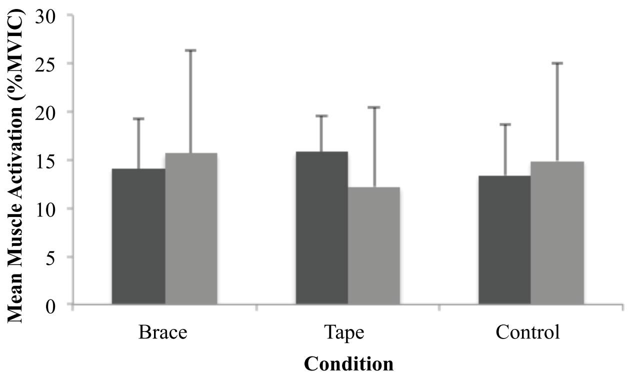

Figure 5: Muscle activation for the gluteus medius muscle in the touch and no-touch groups, and the brace, control and tape conditions. Dark grey bars represent the no-touch group and light grey bars represent the touch group. The condition-by-group interaction was statistically significant ($p<0.0001$), but post-hoc tests were not able to identify which differences were statistically significant. The error bars represent one standard deviation.

activation in the touch condition compared to the no-touch condition ($p=0.005$; Figure 4). For vastus medialis and vastus lateralis, there were no statistically significant condition-by-group interactions, or significant differences between conditions; however, there was significantly less muscle activation in the touch condition compared to the no-touch condition (Figure 4; vastus medialis: $p=0.0469$ and vastus lateralis: $p=0.0287$). Biceps femoris displayed no statistically significant condition-by-group interaction or differences in the effect of touch or between conditions. The condition-by-group interaction for gluteus medius was statistically significant ($p=0.0045$, Figure 5). However, the post-hoc tests were not able to identify which difference(s) were statistically significant. Examination of Figure 5 reveals that the mean amount of gluteus medius activation was similar between the touch and no-touch conditions for brace and control trials (approximately 14% MVIC), but that there was less activation in the touch compared to the no-touch condition in the taped trial, although this difference may not be statistically significant.

Discussion

The purpose of this study was to evaluate whether taping and bracing effectively reduce ankle motion during sudden perturbations in subjects with no injury history and to determine whether taping or bracing alter the timing and peak amplitude of muscle activation following sudden perturbations. We observed no statistically significant differences in peroneus onset between touch and no touch, or between the different taping/bracing conditions. The peak angles in the braced and taped conditions were significantly reduced from the control condition, but were not significantly different from each other. In terms of the taped, braced and control conditions, there were no statistically significant differences in peak muscle activation for seven of the eight muscles; gluteus medius being the exception, although the statistical findings for this muscle were ambiguous (statistically significant interaction, but post hoc tests did not reveal which comparison(s) were significantly different). In terms of the effect of touch, statistically significant reductions in muscle activation were found in four of the muscles that are involved in postural control.

Peroneus onset

We observed no statistically significant differences in peroneus onset between touch/no touch groups, and also between the different conditions. However, our data displayed a trend with shorter onsets in the touch condition for taped and control, and the opposite for the braced condition. Given that the p-value for the interaction in the two-way ANOVA was approaching our threshold for statistical significance, we believe that this may represent a Type II error due to lack of statistical power; a larger sample size might lead to statistically significant differences. While no studies to date have incorporated braced and taped conditions with both inversion and touch platforms, they have compared the effects of bracing and taping on stable and unstable ankles while subjects underwent sudden perturbations [15,16,34]. Previous studies have reported that ankle taping significantly reduced the reaction time to perturbation of the peroneus longus muscle, but only in subjects with chronic ankle instabilities [15,16]. Karlsson and Andreasson [15] noted that the greater the instability, the greater the reduction in response time to sudden inversion; they attributed this to the damaged ligament complex and the improved proprioception acquired by the application of tape. They reported a peroneal onset of 68.8 ms in individuals with stable ankles, which did not significantly change with application of tape. These results are consistent with our study, as we also did not observe any statistically significant differences for average peroneal reaction time to sudden perturbation between the control and taped conditions. During a sudden inversion, ankle structures are stretched which cause reflex muscle activation via proprioceptor activation [35]. This response is weakened in individuals with chronic ankle instability; they must rely on additional stability from either taping or bracing as both techniques provide mechanical stability as well as enhance proprioception in damaged ligaments and joint capsules post-injury [11-13,36]. When the lateral ankle complex is damaged, proprioception is also impaired [37]. These deficits are apparent during balance in single leg stance [38] and in the neuromuscular-activation strategies during walking [39]. The lack of statistically significant differences between taped/braced/control conditions is consistent with previous studies [16,40]. Although one study reported statistically significant delays in the peroneus reflex response in the taping and bracing conditions [17], they did not observe large differences between conditions; their three conditions differed by less than four milliseconds, and they speculated that the changes may not be meaningful in terms of preventing ankle injuries in the healthy athlete with stable ankles. Another study reported no statistically significant differences in tibialis anterior and peroneus longus EMG activity between individuals with or without chronic ankle instabilities when exposed to a sudden inversion stress [40]. We believe that we may not have observed any statistically significant differences between conditions in our study as our subjects were experiencing a ceiling effect with proprioception [41]; they had intact lateral ankle complexes with fully functioning proprioception, and therefore did not benefit from additional cues from either tape or brace. Other researchers have also observed that the muscle responses are different between individuals with chronic ankle instability and healthy controls [39]. Our findings are consistent with previous studies in healthy individuals but contrary to previous studies in subjects with ankle instability. The effect of tape and brace on peroneal reflex onset appears to be a function of ankle stability. Non-elastic tape and braces may improve the neuromuscular response in chronically injured individuals, but not in subjects with uninjured ankles.

Inversion angle

We observed no statistically significant differences in the effect of finger touch on inversion angle, but observed a statistically significant reduction in inversion angle in both the tape and brace conditions compared to control. These results are consistent with the literature, as taping has been found to reduce the end range of motion during inversion perturbations [6,15], and to reduce inversion and eversion range of ankle motion [5]. A previous literature review has acknowledged that many studies reported reduced inversion motion after the application of both brace and tape [3]. Some of the variation between studies may be due to varying effectiveness of different braces and styles of taping. Several studies have reported that taping increases the immediate mechanical stability of the ankle, but that the effect of taping diminishes with increasing duration of exercise [4,6,42-45]. This would lead us to believe that taping should be used for shorter duration events, as well as in events where tape can be reapplied if it loosens during prolonged activity. Our results indicate that both tape and brace were equally effective in limiting excessive ankle inversion during unexpected perturbations. Accordingly, the selection of tape or brace should be based upon factors other than the magnitude of ankle inversion following perturbations; perhaps including factors such as athlete's preference, cost, and the ability to readjust [3].

Muscle activation

We observed no statistically significant effect of brace/tape condition on muscle activation for all eight muscles. These results differ from one study that found significantly higher mean peroneus longus activity in the non-elastic tape trials compared with control [16]. They attributed this result to tape pulling on the skin, increasing proprioception, and thereby eliciting a greater peroneus longus muscle response. This contrast with our study may be because they compared stable and unstable ankles in subjects, while we tested participants with stable ankles with no injury history.

Light finger touch led to statistically significant reductions in peak muscle activation for soleus, tibialis anterior, vastus medialis and vastus lateralis. This reduction was consistent with previous studies [19,46]. Researchers have observed that light finger touch led to a reduction in medial-lateral sway, and inferred that the information provided by fingertip contact permits anticipatory activation of musculature in order to decrease body sway [18]. Several other studies also reported a reduced sway with light finger touch [19-22]. Jeka and colleagues observed differences in subjects with light touch compared to force touch [19,21]. They discovered that the leg muscles play a lesser role in the light touch condition compared to the force condition. They explained that the forces generated in the musculature away from the fingertip (muscles of the trunk and legs, for example) were a result of the sensory information gained by the cutaneous receptors in the fingertip [47] and by proprioceptive information received from the arm [48]. This increase in muscle activation initially seems contradictory to our results that demonstrated reduced muscle activation with light touch, and to the results obtained by Jeka and colleagues [18,19,21] that showed reduced sway with light touch. Jeka [47] explained this discrepancy as additional musculature (trunk and leg muscles, for example) may be recruited with light touch that functions to counteract sway, and that these muscles weren't active during the no touch condition where somatosensory cues were obtained via proprioception at the ankle and feet [47]. The hip abductors (i.e. gluteus medius) regulate medial-lateral sway when standing with a two-leg stance [48], but our results displayed ambiguous statistical findings for the gluteus medius activation as a result of touch; comparable data is lacking as previous studies have not evaluated gluteus medius activation [46]. The differences in response between single stance and bipedal stance can potentially be explained as our subjects were in single-leg stance rather than bipedal stance. Additionally, differences in gluteus medius EMG activity might not have been observed as it is a deep muscle and can be difficult to measure [49]. Ultimately, the fact that light touch led to reduced activation in muscles responsible for regulation of balance speaks to the complexity of balance regulation in the human body. The effect of light touch has great relevance to everyday life. For example, light touch has a profound impact on patients with vestibular deficits [21], neurological conditions [50], and for improvement of balance in individuals who use a cane [21,47].

Limitations and future directions

We were unable to determine differences as a result of leg dominance as only two of the subjects were left leg dominant. Future studies could select adequate numbers of participants with left and right leg dominance in order to determine if the results differ with leg dominance. Our results determined that newly applied non-elastic tape resulted in no significant differences in inversion angle compared with braced conditions. Since we do not know if these changes in muscle activation are maintained as tape slackens with activity, future studies should compare the laxity of tape and brace after substantial use. While our choice of the low-pass filter cutoff frequency was based on previous research [33], our value of 3 Hz will influence the resulting response. Accordingly our results may differ from those that have used other cutoff frequencies. Small sample size was also a limitation. In particular, this may have contributed to our ambiguous statistical findings for the gluteus medius activations. Perhaps we could have had clearer statistical findings if we had tested more subjects. Future studies with larger sample size could provide more power.

Conclusions

The results from our study indicate that both tape and brace are equally effective in limiting excessive motion during an unexpected perturbation in individuals without ankle instabilities. Our results also illustrated that light finger touch significantly decreased muscle activation in the specific muscles related to regulation of standing balance; this highlights the complexity of the neuromuscular system for regulating standing balance in the human body.

Ethical Statement

The University of Western Ontario Human Subjects Research Ethics Board approved the study protocol and all subjects provided written consent prior to participating. No funding was provided which contributed to the development of this manuscript. The authors declare that there are no conflicts of interest.

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