Balance reactions to light touch displacements when standing on foam.

John E. Misiaszek[1,2], Jesse Vander Meulen[1]

[1]Department of Occupational Therapy, Faculty of Rehabilitation Medicine, and [2]Neuroscience and Mental Health Institute, University of Alberta, Edmonton, Alberta, Canada T6G 2G4

Correspondence:
J.E. Misiaszek
Department of Occupational Therapy
2-64 Corbett Hall
University of Alberta
Edmonton, AB
Canada
T6G 2G4

john.misiaszek@ualberta.ca
ph: 780.492.6042
fx: 780.492.4628

Abstract

We hypothesized that standing on an unstable surface would increase the relevance of light touch to standing balance, such that unexpected displacement of a touch reference would result in more consistent expression of balance corrections, compared to standing on a firm surface. Ten healthy participants stood on a foam block atop a force plate without vision, while lightly touching a reference. The touch plate was unexpectedly displaced forwards 10 times. Responses in tibialis anterior (TA) were observed more frequently across the 10 trials compared with standing on a firm surface. However, the responses evoked in trials 2-10 were functionally distinct from those following the first trial. We suggest the first trial responses represent balance corrective responses induced by the slip of the finger relative to the reference. In contrast, the subsequent responses in TA are likely related to an arm-tracking reaction that emerges, indicating a rapid repurposing of the tactile feedback.

Highlights

- Balance corrections are induced by the first touch displacement when standing on foam.
- An arm-tracking behaviour emerges with subsequent touch displacements.
- Light touch feedback is rapidly repurposed to meet the needs of the task.

Keywords: touch; balance; standing; posture; haptic; human

Introduction

Lightly touching a stable reference reduces sway during standing, particularly in the absence of vision [1]. It is argued that shear forces at the fingertip provide feedback about the direction, extent and speed of sway [1,2]. Furthermore, sway becomes entrained to an oscillating contact surface [3,4,5]. Taken together these findings suggest that sensory feedback from the fingertip encodes sway when a contact surface is expected to be a stable reference point.

Recently, we demonstrated that unexpected displacement of a touch reference evoked postural responses (PRs) in muscles of the ankle in approximately 60% of naïve participants [5]. However, responses at the ankles were only observed following the first trial. It was suggested that the lack of PRs in some participants and the absence of PRs on repeated trials reflected a context-dependent weighting of the tactile feedback. That is, the contribution of tactile feedback to balance control likely depends upon the perceived relevance of the feedback to the performance of the task. If so, then increasing the relevance of the fingertip tactile feedback to the task of maintaining standing balance should result in more consistent expression of PRs across participants and with repeated exposures.

A common approach to increasing the postural demands is to introduce a compliant surface, such as a block of foam. Standing on foam increases sway that is further exacerbated in the absence of vision [6,7]. This increased sway is argued to arise from two factors. First, the foam redistributes pressure beneath the feet leading to a decrease in peak pressure and an increase in the contact area [8], leading to impaired, or at least unfamiliar, sensory feedback from the feet and ankles [9]. Second, the forces generated to stabilize sway compress the viscoelastic surface creating unexpected mechanical perturbations both when the compressive load is applied and released [10]. Light fingertip touch reduces sway when standing on foam, particularly when vision is also occluded [7]. Dickstein et al. [7] argued that deficiencies in both surface and visual information are compensated for by increasing the weighting of the fingertip tactile feedback.

The objective of the present study was to increase the relevance of light touch feedback to the maintenance of posture by introducing a compliant surface. We expected that displacement of a light touch contact would more consistently evoke PRs at the ankle, compared with standing on a firm surface [5]. We further hypothesized that PRs at the ankles would be observed in more than just the first trial.

Methods

Participants

Ten healthy volunteers (age range 20-25; 7 female, 3 male) provided written consent for participation in a protocol approved by the University of Alberta Research Ethics Board. It was essential that participants were unaware that the touch reference would be displaced. Therefore, participants were screened to verify they were unaware of the study's true purpose. Full disclosure was provided after the experimental session and participants were provided the opportunity to withdraw their consent.

Set-up and apparatus

Participants stood in stocking feet, shoulder width apart, on an ethylene-vinyl acetate (EVA) pad placed atop a force plate (AMTI OR6-7-1000). The 47.5 cm x 37.5 cm x 5 cm EVA pad was centered on the 50.8 cm x 46.4 cm surface of the force plate. The position of the feet was marked to ensure consistent placement for each task.

In some tasks participants were asked to touch a brushed aluminum plate (3.75 cm wide x 7.5 cm long). The touch plate was positioned so that the tip of the right index finger was centered on the plate, with the finger bent such that the distal phalanx was vertical, the forearm was in a horizontal posture, and the upper arm was vertical, such that the elbow was approximately 90º. The other fingers and thumb were curled into the palm to prevent contacting the plate. The left arm was free to hang naturally.

The touch plate was mounted upon a positioning stage (LinTech 130 Series) driven by a two-phase stepper motor (Applied Motion Products 5023-124). The entire apparatus was mounted on a force transducer (AMTI MC3A-100) to measure the vertical load applied by the participant when touching the plate. Participants received an auditory cue if the applied force exceeded 1 N. White noise was delivered through noise-canceling headphones during all trials to mask any sounds created by the motor.

Protocol

It was important for participants to perceive the touch plate as a stable reference. Therefore, participants performed three sham tasks prior to the experimental task: standing on foam with a) eyes open and both hands at their sides, b) eyes open while lightly touching the touch plate, and c) both hands at their sides, but with their vision occluded by darkened goggles. Each sham task was performed for 2 min. For the fourth, experimental task participants stood on foam with occluded vision while lightly touching the touch plate. After approximately 30s, the touch plate was unexpectedly displaced 12.5 mm, with a peak velocity of 124 mm/s. Ten such displacements were delivered. Between displacements the touch plate was slowly (2.5 mm/s) returned to the starting position while the participant maintained contact. The touch plate remained stationary 2-8 s before the next displacement. All displacements were in the forward direction. The fourth task required approximately 10 min to complete.

Data collection and analysis

Electromyographic (EMG) recordings were obtained from right anterior deltoid (AD), posterior deltoid (PD), sternocleidomastoid (SCM), tibialis anterior (TA), and soleus (SOL). Two Ag-AgCl surface electrodes (NeuroPlus A10040) were placed over the bellies of the muscles, aligned to the predicted path of the muscle fibers, with an inter-electrode distance of 2 cm. Ground electrodes were placed over the clavicle and tibia. EMG signals were amplified and band-pass filtered (30 Hz – 1 kHz, 60 Hz notch, Grass P511 amplifiers, Astro-Med) prior to digitization. Electrogoniometers (Biometrics, Newport, UK) were placed across the right ankle and elbow joints. All signals were digitized at 4 kHz (National Instruments PCI-MIO-16E-4). Data analysis occurred offline using custom-written LabView v8.2 routines. EMG signals were digitally full-wave rectified and then low-pass filtered at 50 Hz (dual-pass 2^{nd} order Butterworth). The mechanical signals were low-pass filtered at 20 Hz. The center of pressure (COP) position was calculated from the force plate force and moment.

To determine if touch plate displacement evoked EMG responses a two standard deviations band around the mean EMG activity for the 100 ms prior to the perturbation was calculated. A response was considered present if the EMG trace exceeded this band for at least 20 continuous milliseconds. Responses with onset latencies >200 ms were not considered for further analysis, in keeping with the procedures of Misiaszek et al. [5]. Response amplitudes were calculated as the mean rectified EMG for the first 75 ms of the response, normalized to maximum voluntary contraction (MVC). Participants swayed considerably while standing on the foam making it unfeasible to estimate perturbation-related sway in the COP data using the two standard deviations band approach. As shown in Fig. 3A, perturbation-related sway events were apparent in some trials (particularly the first trial). To determine if the perturbations induced systematic changes in COP position, the change in COP position 300 ms following the onset of the touch plate displacement relative to the position at perturbation onset was calculated for each trial. The change in COP position was calculated for all trials. Changes in joint angles were also estimated using this approach.

Statistical Procedures

The frequency of responses while standing on foam were compared to the data reported in [5] for standing on a firm surface. Fisher's Exact Tests were used to compare the response frequencies for each muscle following the first trial between the firm and foam surfaces. Fisher's Exact Tests were also used to compare the response frequencies in trials 2 through 10 between surface types. To determine if response latencies and amplitudes varied with repeated trials the first identified response was compared to the last identified response from a participant using two-tailed paired *t*-tests. The first and last responses need not have been the first and tenth trials. Data were excluded from this analysis if fewer than 2 responses were observed in a given muscle for a participant. Two-tailed paired *t*-tests compared average onset latencies between TA and AD. Two-tailed single sample *t*-tests compared the change in COP_{A-P} position, change in ankle angle, and change in elbow angle, against hypothesized values of 0 (no change). Two-tailed Student's *t*-tests compared background EMG in TA, SOL and AD from the current study against data from standing on a firm surface [5]. Significant differences were identified when $p < 0.05$.

Results

Unexpected forward displacement of the light touch reference evoked short latency responses in TA and/or AD when participants stood on foam. Figure 1 shows EMG traces from TA for a single participant that generated a clear response following the first exposure to the displacement (trial 1) with an onset latency of 117.5 ms. Comparable responses were observed with subsequent trials, including the 10th trial (with onset latencies ranging between 98.25 – 119.75 ms).

EMG response frequency

Figure 2 summarizes the response occurrence across participants. TA responses were evoked in all participants at least twice across the 10 trials. At least 1 response was observed in AD of all but 1 participant. First trial responses were observed in TA in 6 of 10 participants, which was identical to the proportion of first trial responses previously observed (12 of 20 participants) while standing on a firm surface. In addition, 2 of 10 participants responded with AD on the first trial, compared with 10 of 20 when standing on a firm surface resulting in a Fisher's Exact p=0.235. In subsequent trials (trials 2-10), responses in TA were observed more frequently (Fisher's Exact p<0.001) across all participants when standing on foam (62 of 90 trials), than when standing on a firm surface (0 of 180 trials). AD activation was observed less frequently (Fisher's Exact p<0.001) in subsequent trials while standing on foam (45 of 90 trials), compared with standing on a firm surface (133 of 180 trials). Responses in SCM were rare, with only 1 response observed across all 100 trials.

EMG response latency and amplitude

The average latency of TA responses was 102.3 ± 14.25 ms (mean ± s.d.) across all trials and participants. There was no apparent change in TA response latency with repeated trials as the average latency of the first evoked response (104.9 ± 23.95 ms) was not different ($t_{(9)}$=0.36, p=0.73) from the last evoked response (106.8 ± 22.17 ms) across participants. Responses evoked in AD had an average latency of 81.4 ± 23.68 ms across all trials and participants. A paired comparison of the average latency of TA against AD indicated that the AD responses had a shorter latency ($t_{(8)}$=2.93, p=0.019). Repeated trials did not affect latencies of the AD responses as the average latency of the first evoked response (86.7 ± 26.17 ms) was not different ($t_{(8)}$=0.69, p=0.51) from the last evoked response (80.1 ± 23.30 ms) across participants.

Response amplitudes did not systematically vary with repeated trials. The average amplitude of the first response in TA was 1.4 ± 1.55 %MVC, which was not different ($t_{(9)}$=0.70, p=0.50) from the last response of 1.9 ± 2.23 %MVC. The average amplitude of the first response in AD of 5.7 ± 4.55 %MVC was not different ($t_{(8)}$= 1.61, p=0.15) from the last response of 4.6 ± 4.47 %MVC.

Background EMG activity did not systematically vary with repeated trials. The average background activity in TA prior to the first trial (3.5 ± 0.53 %MVC) was not different ($t_{(9)}$=0.71, p=0.50) to the last trial (3.7 ± 1.51 %MVC). The average background activity in SOL prior to the first trial (17.4 ± 6.81 %MVC) was also not different ($t_{(9)}$=0.71, p=0.50) to the last trial (15.4 ± 3.04 %MVC). The average background activity in AD prior to the first trial (4.7 ± 2.84 %MVC) was not different ($t_{(9)}$=0.55, p=0.60) to the last trial (5.13 ± 4.10 %MVC). Standing on foam did not overtly influence the background activity in TA or AD. The average background activity in TA was 3.3 ± 0.81 %MVC (firm) and 3.6 ± 0.75 %MVC (foam), which were not different (Student's $t_{(29)}$=0.86, p=0.40). The average background activity in AD was 4.4 ± 1.54 %MVC (firm) and 4.3 ± 2.20 %MVC (foam), which were not different ($t_{(29)}$=0.11, p=0.91). In contrast, background activity in SOL increased ($t_{(29)}$=2.37, p=0.025) when standing on foam (17.0 ± 4.15 %MVC), compared with standing on a firm surface (13.3 ± 3.98 %MVC).

$COP_{A\text{-}P}$, elbow and ankle angles

Figure 3A depicts traces from one participant. The traces are vertically aligned to the position at the time of perturbation onset (0 ms). As can be seen, the consequences of the first trial (thick grey traces) are distinctly different from the subsequent trials (thin black traces).

Following the first trial there is a distinct forward sway of the COP_{A-P}, beginning at about 200 ms. Following subsequent trials the position of the COP_{A-P} appears to either be unaffected, or sway backwards. The elbow joint exhibits a distinct flexion at 200 ms in the first trial, but is extended in later trials. The ankle joint shows a modest dorsiflexion at 200 ms in the first trial, but little reaction in subsequent trials.

To characterize the adaptation in mechanical events with repeated trials the change in COP_{A-P} position, elbow angle and ankle angle was determined 300 ms following the perturbation onset, relative to the positions at perturbation onset. The average changes in COP_{A-P} position and joint angles across participants are depicted in Figure 3B. It can be seen that the first trial resulted in distinctly different outcomes than the subsequent trials. Specifically, the COP_{A-P} position indicates that all participants swayed forwards on the first trial. Thereafter a consistent pattern of sway was not observed resulting in a change in COP_{A-P} position near zero, with relatively large variability. The mean change in COP_{A-P} for the first trial was 2.9 ± 1.12 mm, which is significantly different from a hypothesized value of 0 mm ($t_{(9)}$=8.16, p<0.001). In contrast, the mean change in COP_{A-P} for the tenth trial was -1.3 ± 2.67 mm, which is not different from 0 mm ($t_{(9)}$=1.56, p=0.15). The elbow flexed following the first trial across all participants with an average change in angle of -1.7 ± 1.97°, significantly less than a hypothesized value of 0° ($t_{(9)}$=2.67, p=0.026). However, for all subsequent trials the elbow extended or demonstrated very little difference 300 ms following the displacement. For the tenth trial, this resulted in an average change in angle of 2.2 ± 1.61°, which is significantly greater than 0° ($t_{(9)}$=4.41, p=0.0017). All participants demonstrated a modest dorsiflexion following the first trial, resulting in an average change in ankle angle of -0.3 ± 0.39° 300 ms following the displacement, which was different from 0° ($t_{(9)}$=2.35, p=0.043). In contrast, the change in ankle angle on subsequent trials varied across participants and trials. As a result, the average tended be a positive difference, or plantarflexion, but not much different from 0°. The tenth trial average change in angle across participants was 0.1 ± 0.43°, not different from 0° ($t_{(9)}$=0.68, p=0.52).

Discussion

As observed previously, only about 60% of participants react to the first exposure of a touch displacement with activation of TA [5]. Increasing the instability by standing on foam did not change this rate. The evoked responses in TA on the first touch plate displacement likely represent a PR [5]. The short-latency responses in TA precede a forward sway in the COP_{A-P} and dorsiflexion at the ankle, coupled with flexion at the elbow. This behaviour is consistent with a reaction that would correct for a backwards fall. That is, a backwards fall would result in a relative forward displacement of the touch. Activation of TA would counteract a backwards fall, dorsiflexing the ankle and drawing the body forward. The coincidental flexion at the elbow is likely a coordinated response integrated within the PR to ensure contact with the touch reference is maintained [11].

Subsequent exposures (trials 2-10) of the touch displacement evoked a change in behaviour that we suggest represents an arm-tracking strategy [5]. An arm-tracking strategy is suggested by the increased prevalence of evoked responses in AD and progressive arm extension behaviour. In addition, the consistent forward sway observed after the first trial was no longer apparent. Interestingly, all participants exhibited responses in TA in trials 2-10 when standing on foam, in stark contrast to the lack of responses for participants standing on a firm surface [5]. The increased occurrence of responses in TA was not due to greater activation of TA when standing on foam as background TA activity was comparable to that seen when standing on a firm surface. It is possible that the activity in TA during the emergence of the arm-tracking strategy is related to an “associated postural adjustments” (APA) accompanying the focal arm movements [12,13]. However, muscle activity associated with APAs typically precedes that of the focal movement, which was not observed here, and activation of TA is not typically associated with APAs with arm extension behaviours. The functional relevance of the TA activation in trials 2-10 is not easily delineated. Nevertheless, it is apparent that TA is activated in subsequent trials when standing on an unstable surface and is incorporated as part of a distinctly different behaviour than what is observed with the first trial.

PRs typically demonstrate first trial effects wherein the initial exposure to a disturbance evokes responses that are larger in amplitude than subsequent trials, but with generally unaltered timing [14]. The first trial responses we report do not appear to be consistent with typical first trial effects as the forward sway response is abandoned and arm-extension replaces an initial arm-flexion response. Therefore, this is not a simple habituation process. It is possible that the displacement of 12.5 mm was large enough to allow the participants to become aware of the first disturbance so as to lead them to disregard future perturbations. Following the experiment all participants were asked to describe their experience, including indicating if they detected any disturbances. Indeed, by the last trial all participants identified that the touch plate moved. However, most participants (8/10) indicated fewer than 5 displacements. Moreover, consistent with our previous study [5], some participants initially believed the support surface had moved. These anecdotal accounts make it unlikely that the change in behaviour after the first trial is the result of conscious awareness of the nature of the initial disturbance. Alternatively, it might be that the first trial responses observed here are startle responses. It was recently argued that PRs include a startle component [15]. However, startle typically evokes responses in SCM (including from balance disturbances [15,16]), which was not observed here. In addition, the startle component to first trial responses appears to amplify an underlying PR [15]. The first trial response we observed was a distinctly different behaviour from the subsequent trials, making it unlikely that the difference can be explained by a startle component alone.

The most striking finding of this study is the immediacy with which participants changed their motor response after the first trial. The change in behaviour was robust even though the stimulus did not change (slip of the touch plate) and no instructions were offered to the participants. Nevertheless, all participants subsequently utilized the tactile cue to “trigger” an arm-tracking task. For those participants that initially engaged a PR, this required identifying that their response was functionally inappropriate and then quickly determining an alternative solution to the problem posed by the slip-related tactile feedback. This rapid “repurposing” of the tactile cues is worthy of further study as the selection of appropriate motor responses and the ability to quickly adapt based upon experience are important to meet the needs of maintaining stability in challenging environments. The problem is similar to that faced in other motor tasks, such as reaching, when multiple possible movements might be considered, before one is decided upon and implemented [17]. It has been suggested that when such challenges are encountered multiple motor solutions are encoded in parallel before selecting the one that is implemented [18]. A similar process could explain the rapid nature by which participants switched from a PR strategy to an arm-tracking strategy in the present study.

Acknowledgements

This work was supported by a grant from the Natural Sciences and Engineering Research Council (Canada) to JEM.

References

[1] J.J. Jeka, J.R. Lackner, Fingertip contact influences human postural control, Exp Brain Res 100 (1994) 285-301.

[2] S. Clapp, A.M. Wing, Light touch contribution to balance in normal bipedal stance, Exp Brain Res 125 (1999) 521–524.

[3] J.J. Jeka, K. Oie, G. Schoner, T. Dijkstra, E. Henson, Position and velocity coupling of postural sway to somatosensory drive, J Neurophysiol 79 (1998) 1661–1674.

[4] A.M. Wing, L. Johannsen, S. Endo, Light touch for balance: influence of a time-varying external driving signal, Philos Trans R Soc Lond B Biol Sci 366 (2011) 3133–3141.

[5] J.E. Misiasek, J. Forero, E. Hiob, T. Urbanczyk, Automatic postural responses following rapid displacement of a light touch contact during standing, Neurosci 316 (2016) 1-12.

[6] N. Chaikeeree, V. Saengsirisuwan, B. Chinsongkram, R. Boonsinsukh, Interaction of age and foam types used in Clinical Test for Sensory Interaction and Balance (CTSIB), Gait Posture 41 (2015) 313-315.

[7] R. Dickstein, C.L. Shupert, F.B. Horak, Fingertip touch improves postural stability in patients with peripheral neuropathy, Gait Posture 14 (2001) 238-247.

[8] G. Wu, J.-H. Chiang, The effects of surface compliance on foot pressure in stance, Gait Posture 4 (1996) 122-129.

[9] J.-H. Chiang, G. Wu, The influence of foam surfaces on biomechanical variables contributing to postural control, Gait Posture 5 (1997) 239-245.

[10] M. Patel, P.A. Fransson, D. Lush, S. Gomez, The effect of foam surface properties on postural stability assessment while standing, Gait Posture 28 (2008) 649-656.

[11] P.J. Cordo, L.M. Nashner, Properties of postural adjustments associated with rapid arm movements, J Neurophysiol 47 (1982) 287-302.

[12] S. Bouisset, M. Zattara, A sequence of postural movements precedes voluntary movement, Neurosci Lett 22 (1981) 263-270.

[13] W.G. Friedli, M. Hallett, S.R. Simon, Postural adjustments associated with rapid voluntary arm movements 1. Electromyographic data, J Neurol Neurosurg Psych 47 (1984) 611-622.

[14] J.H.J. Allum, K.-S. Tang, M.G. Carpenter, L.B. Oude Nijhuis, B.R. Bloem, Review of first trial responses in balance control: Influence of vestibular loss and Parkinson's disease, Hum Mov Sci 30 (2011) 279-295.

[15] A.D. Campbell, J.W. Squair, R. Chua, J.T. Inglis, M.G. Carpenter, First trial and StartReact effects induced by balance perturbations to upright stance, J Neurophysiol 110 (2013) 2236-2245.

[16] L.B. Oude Nijhuis, J.H.J. Allum, J. Valls-Solé, S. Overeem, B.R. Bloem, First trial postural reactions to unexpected balance disturbances: A comparison with the acoustic startle reaction, J Neurophysiol 104 (2010) 2704-2712.

[17] P. Cisek, Cortical mechanisms of action selection: the affordance competition hypothesis, Philos Trans R Soc Lond B Biol Sci 362 (2007) 1585-1599.

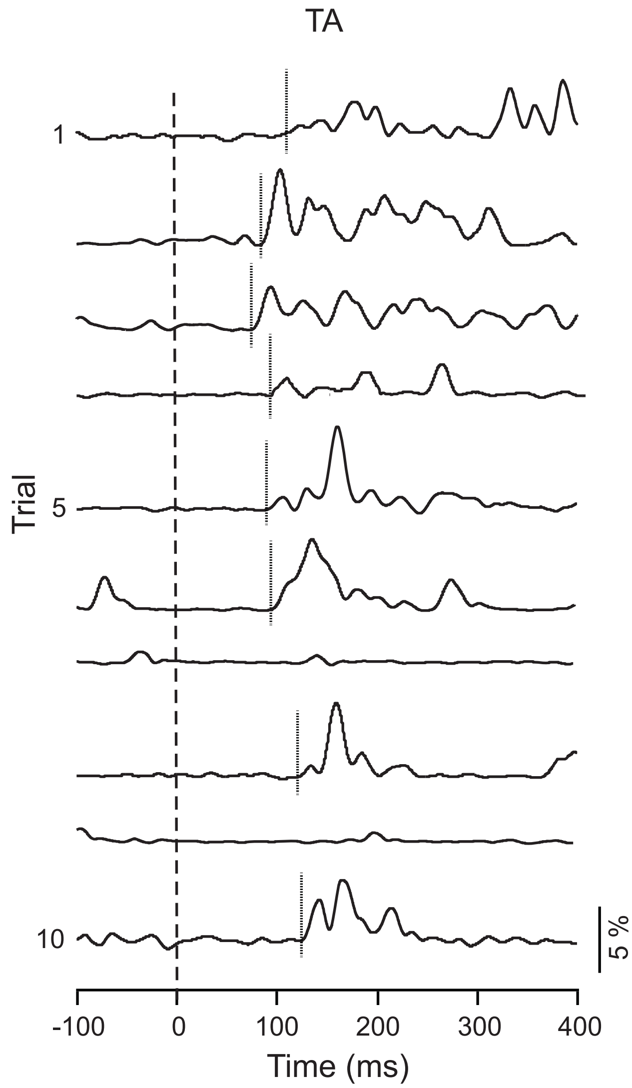
[18] J.P. Gallivan, L. Logan, D.M. Wolpert, J.R. Flanagan, Parallel specification of competing sensorimotor control policies for alternative action options, Nat Neurosci 19 (2016) 320-326.

Figure Legends

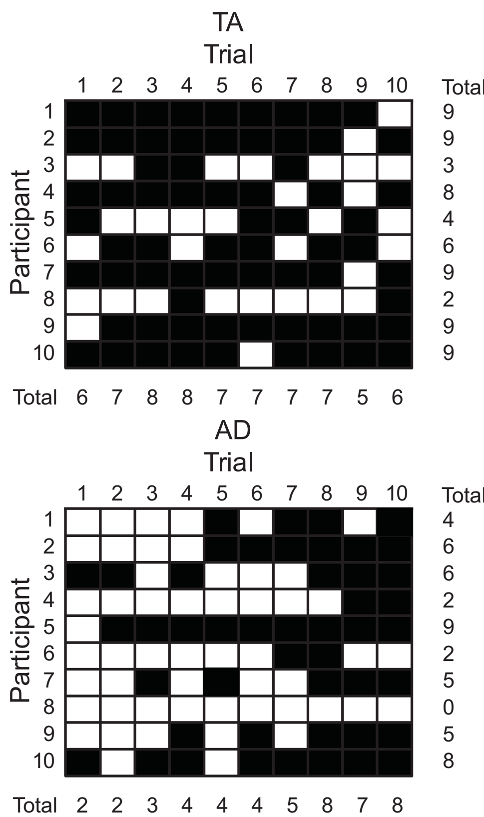
Figure 1 Data traces from one participant (participant #4) showing the EMG activity in TA for all 10 forward touch plate displacements. Each full-wave rectified and low-pass filtered (50 Hz) EMG trace begins 100 ms prior to the onset of the touch plate displacement (indicated by the vertical dashed line). The small vertical lines indicate the onset of an evoked response in each trace when present. The EMG scale bar represents 5% MVC.

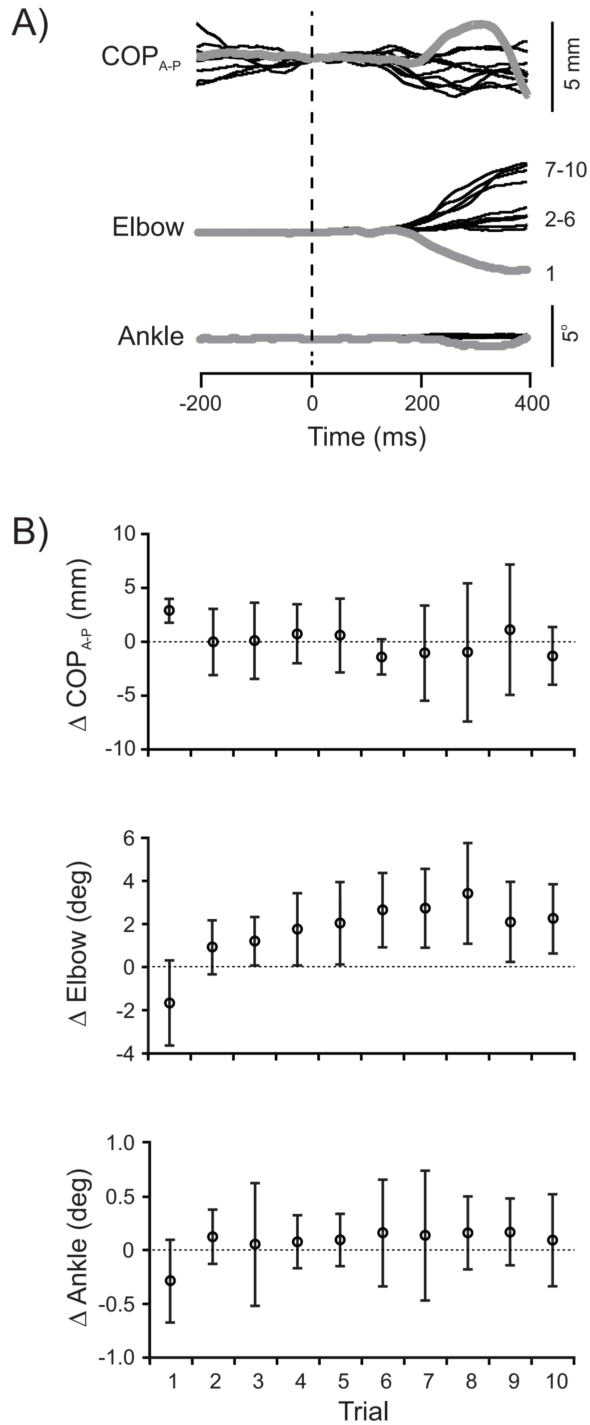
Figure 2 Grid indicating the presence of detectable EMG responses in TA and AD following forward touch plate displacements across all participants and trials. The darkened cells indicate trials for which a response was present.

Figure 3 (A) Data traces from one participant showing the $COP_{A\text{-}P}$, Elbow and Ankle angles for all 10 forward touch plate displacements. The first trial is depicted as the thick grey trace, while trials 2-10 are depicted as the thin black traces. Each trace begins 200 ms prior to the onset of the touch plate displacement (indicated by the vertical dashed line) and has been aligned vertically to the position at displacement onset. (B) Group averages of the change in $COP_{A\text{-}P}$, Elbow and Ankle angles 300 ms after touch plate displacement onset. Error bars indicate standard deviation. The dashed horizontal line indicates no change. Positive values in the $COP_{A\text{-}P}$ data represent forward differences, while positive values in the joint angles represent extension and plantarflexion.



TA
Trial
1
5
10
5 %
-100
0
100
200
300
400
Time (ms)


TA
Trial
1 2 3 4 5 6 7 8 9 10
Total
Participant
1 2 3 4 5 6 7 8 9 10
9 9 3 8 4 6 9 2 9 9
Total 6 7 8 8 7 7 7 7 5 6
AD
Trial
1 2 3 4 5 6 7 8 9 10
Total
Participant
1 2 3 4 5 6 7 8 9 10
4 6 6 2 9 2 5 0 5 8
Total 2 2 3 4 4 4 5 8 7 8



A)
COP_{A-P}
5 mm
7-10
Elbow
2-6
1
Ankle
5°
-200
0
200
400
Time (ms)
B)
Δ COP_{A-P} (mm)
10
5
0
-5
-10
Δ Elbow (deg)
6
4
2
0
-2
-4
Δ Ankle (deg)
1.0
0.5
0
-0.5
-1.0
1
2
3
4
5
6
7
8
9
10
Trial