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Modulation of tendon tap reflex activation of soleus motor neurons with reduced stability tandem stance

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ABSTRACT

Reduced stability while standing typically decreases the soleus muscle Hoffmann (H-) reflex amplitude, purportedly to prevent the Ia afferent signal from excessively activating spinal motor neurons during the unstable stance. H-reflex measures, however, by excluding the spindle do not reflect the actual effect of the Ia pathway (i.e. the combined effects of spindle sensitivity and Ia presynaptic inhibition) on motor neuron activation, as tendon tap reflex measures can. But the effect of stance stability on soleus muscle tendon tap reflex amplitude is largely unknown. This study examined 30 young adults (mean(s), 21(2) years) as they stood in a wide stable stance position and an unstable tandem stance with a reduced base of support. Standing body sway, the amplitude of the soleus muscle tendon tap reflex, background EMG and tap force were measured in both stances. A repeated measured design *t*-test was calculated for each variable. Most subjects (69%) decreased tendon tap reflex amplitude when in the tandem stance position (mean decrease 11.6%), compared to the wide stance (wide stance 0.248(0.124) mV, tandem stance 0.219(0.119) mV, $p < 0.05$, Cohen's $d = 0.24$ small) with no significant differences in background soleus and tibialis anterior EMG, and tap force across the stances. There was no relationship between the modulation of the tendon tap reflex amplitude across the stances and standing body sway in the tandem stance. Results support the idea that for most subjects examined, during a less stable stance the Ia excitation of motor neurons is decreased, likely by presynaptic inhibition, thereby avoiding potential instability in the reflex loop or saturating the reflex pathway and possibly interfering with descending control of the involved spinal motor neurons.

1. Introduction

When a person maintains a standing position with reduced stability due to a reduced base of support or an unstable surface the soleus Hoffmann (H-) reflex amplitude is typically decreased (Chalmers & Knutzen, 2002; Chen & Zhou, 2011; Day, Boivin, Adkin, & Tokuno, 2017; Huang, Cherng, Yang, Chen, & Hwang, 2009; Kim, Hart, & Hertel, 2013; Pinar, Kitano, & Koceja, 2010; Solopova, Kazennikov, Deniskina, Levik, & Ivanenko, 2003; Trimble & Koceja, 2001). The H-reflex decrease, with unchanged soleus and tibialis anterior (TA) activity, is due to increased pre-synaptic inhibition (PSI) of the Ia afferent signal during the more challenging stance (Chen & Zhou, 2011; Enoka et al., 2011; Enoka et al., 2011). The greater Ia PSI is believed to stabilize the posture by preventing the spindle afferent signal from excessively activating spinal motor neurons, and so allowing for greater motor neuron control by

Abbreviations: H-reflex, Hoffmann reflex; TA, tibialis anterior; PSI, pre-synaptic inhibition; bEMG, background EMG; CoP, center of pressure; ML, medial to lateral; AP, anterior to posterior

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supraspinal centers (Chen & Zhou, 2011; Day et al., 2017; Enoka et al., 2011; Kim et al., 2013; Llewellyn, Yang, & Prochazka, 1990; Pinar et al., 2010; Sefton, Hicks-Little, Koceja, & Cordova, 2007; Solopova et al., 2003).

Electrically elicited H-reflex measures, however, do not fully represent naturally occuring Ia afferent input to motor neurons because the H-reflex is more affected by PSI than the stretch reflex (elicited by ankle dorsiflexion) or the tendon tap reflex is (Morita, Petersen, Christensen, Sinkjaer, & Nielsen, 1998) and the H-reflex excludes the spindle with its variable sensitivity. For example, if soleus spindle sensitivity were increased while in an unstable stance, the resulting increase in the Ia afferent signal could produce an increase in the activation of spinal motor neurons despite an increase in Ia PSI and reduced H-reflex amplitude. The possibility for soleus spindle sensitivity to be enhanced during difficult stances exists due to human studies indicating increased spindle sensitivity during attention to precise ankle movements (Hospod, Aimonetti, Roll, & Ribot-Ciscar, 2007; Ribot-Ciscar, Hospod, Roll, & Aimonetti, 2009). Consequently, H-reflex modulation during some motor tasks does not reveal operation of the stretch or tendon tap reflex (Horslen, Murnaghan, Inglis, Chua, & Carpenter, 2013; Nafati, Rossi-Durand, & Schmied, 2004; Sinkjaer, Andersen, & Larsen, 1996). Accordingly, stretch or tendon tap reflex measures should be used to assess the premise (Chen & Zhou, 2011; Day et al., 2017; Enoka et al., 2011; Llewellyn et al., 1990; Enoka et al., 2011) that during a precise position control task, control of the Ia signal will prevent the Ia activation of spinal motor neurons from increasing to the point of potentially excessively activating the spinal motor neurons, resulting in instability in the reflex loop or saturating the reflex pathway and interfering with descending control of the motor neurons. Muscle stretch or tendon tap reflex measures reflect the combined effects of the spindle generated Ia signal and the PSI the Ia signal experiences (assuming other influences such as bEMG are controlled), and do not separate or identify the individual effects of or modulation of PSI and/or spindle sensitivity.

Unfortunately, in contrast to much data on soleus H-reflex modulation during reduced base of support or unstable surface standing tasks (Chalmers & Knutzen, 2002; Chen & Zhou, 2011; Day et al., 2017; Huang et al., 2009; Pinar et al., 2010; Solopova et al., 2003; Trimble & Koceja, 2001; Chalmers & Knutzen, 2002) information on soleus short latency stretch or tendon tap reflex modulation when standing instability increases is sparse. A sit or supine to stand transition increased the soleus short latency stretch reflex, with no change in background EMG (bEMG) (Obata, Kawashima, Ohtsuki, & Nakazawa, 2012; Shimba, Kawashima, Ohta, Yamamoto, & Nakazawa, 2010). The only study comparing two stances with differing stability found that the Achilles tendon tap reflex is reduced when removing hand support during stance (Elner, Gurfinkel, Lipshits, Mamasakhlisov, & Popov, 1976) but this is not directly comparable to H-reflex studies which have examined reflex modulation with a reduced or unstable base of support. Previous studies have examined the operation of the Achilles tendon stretch or tendon tap reflex while subjects stood (Corna, Galante, Grasso, Nardone, & Schieppati, 1996; Nardone, Corra, & Schieppati, 1990; Woollacott & Nashner, 1982), but not during stances differing in stability. Human triceps surae short latency stretch reflex modulation has been examined under conditions of increased ankle load instability in seated subjects controlling only ankle movement (Finley, Dhaher, & Perreault, 2012). A reduced reflex amplitude that attenuated short latency stretch reflex contribution to ankle stability during the seated unstable ankle load conditions was found (Finley et al., 2012). The authors (Finley et al., 2012) conjectured that the results would apply to unstable standing conditions, but that idea has not been tested until now.

The primary purpose of this study was to determine the modulation of the soleus short latency tendon tap reflex amplitude when standing posture changes from a wide stable stance to a less stable narrow tandem stance. It was theorized that while in the less stable tandem stance a spindle sensitivity enhancement may occur, resulting from the increased attention and position precision demands of the difficult stance (Enoka et al., 2011; Nafati et al., 2004; Prochazka, Hulliger, Trend, & Dürmüller, 1988; Ribot-Ciscar et al., 2009). The effect of the spindle Ia firing on spinal motor neurons, however, would be inhibited by an increased PSI of the Ia signal known to occur during an unstable stance (Chen & Zhou, 2011; Enoka et al., 2011). The primary null hypothesis was that there would be no difference in the tendon tap reflex amplitude under the conditions of wide versus less stable tandem stance. The primary alternate hypothesis was that a decrease in tendon tap reflex amplitude would be observed in the tandem stance, similar to that observed for the H-reflex, indicating that the nervous system prevents the spindle Ia activation of the spinal motor neurons from being increased when in the unstable tandem stance.

While group averages show a decrease in H-reflex amplitude with greater stance instability, some individuals do not follow this trend. In elderly subjects there is a positive relationship between H-reflex amplitude modulation and magnitude of standing sway, revealing that subjects with greater standing body sway increased their H-reflex when stance instability increased with a prone to standing transition, while subjects with lower levels of standing body sway depressed the H-reflex (Koceja, Markus, & Trimble, 1995). A similar pattern was found in young adults where those with less steady standing balance on a teeter board increased their H-reflex amplitude when the base of support was reduced, while subjects with more steady standing balance decreased their H-reflex amplitude under the same conditions (Kawaishi & Domen, 2016). Accordingly, a secondary experimental hypothesis was that a positive relationship would be found between the wide to tandem stance modulation of tendon tap reflex amplitude and standing body sway when in the tandem stance, as observed for the H-reflex. Further, similar to the H-reflex, subjects with greater standing body sway would tend to increase their tendon tap reflex when stance instability increased, while subjects with lower levels of standing body sway would tend to depress their reflex.

2. Methods

2.1. Participants

Thirty subjects (9 male, 21 female; age (mean(standard deviation)): 21(2) years, age range: 19–27 years) with no neuromuscular pathologies, extensive athletic or dance experience, or neuromuscular medications participated. All subjects abstained from nonprescription drugs and alcohol use for 24 h prior to testing. The experiments were approved by the Institutional Human Subjects Ethics Committee and subjects gave informed consent prior to testing.

2.2. Experimental procedures and data acquisition

With subjects bare footed, a digital goniometer (± 0.5° precision, Baseline Absolute Axis, Fabrication Enterprises, Inc., White Plains, NY U.S.A.) was securely attached to the lateral aspect of the subject's right leg, with the goniometer axis of rotation over the lateral malleolus. The metal goniometer body was placed along the long axis of the lower leg shank. The other goniometer arm, replaced with a plastic arm rigid in the ankle dorsi and plantar flexion direction but flexible in other directions to allow unconstrained foot movements, was attached to the long axis of the foot. The purpose of the goniometer was to ensure that the ankle angle was kept within a narrow range (defined below) when soleus reflex measures were being made because stretch reflex amplitude varies with static joint angle (Lin, Brown, & Walsh, 1997), the goniometer was not used to determine body sway. The standing body sway of subjects was assessed using a force plate and Balance Clinic software (AccuGait, AMTI, Watertown, MA U.S.A.) prior to the commencement of reflex measures. Standing body sway was measured in wide stance (standing with feet spaced at a preferred distance apart, with the heel of the left foot in line with the toes of the right foot), and tandem stance (standing with the left foot placed directly in front of, and with heel touching the toes of, the right foot). The placement of the left foot in front of the right foot while in the wide stance was specified so that when shifting between the wide and tandem stances there would be a negligible change in right ankle angle. Subjects stood with arms held loosely at the sides, distributed weight equally across both feet, kept knees straight, avoided any muscle contractions other than those needed to maintain the standing position, and focused on a circle 2 m ahead. Each stance position, held for 30 s while center of pressure (CoP) data were collected at 50 Hz, was assessed three times in a random sequence, with at least 30 s of seated rest between trials (Clark et al., 2010; Gray, Ivanova, & Garland, 2014; Raymakers, Samson, & Verhaar, 2005). Subjects were instructed to stand as still as possible and a trial was invalid if a foot moved, and the trial was repeated.

Skin at the right leg electrode sites was cleaned, and EMG recording electrodes (Delsys Bagnoli, Natick, MASS U.S.A.) were placed on the soleus, along the midline of the dorsal aspect of the leg with the proximal electrode 1 cm distal to medial head of the gastrocnemius, and on the TA muscle, one third of the distance from the patella to the lateral malleolus (Zipp, 1982). A ground electrode was attached to the right wrist. Muscle EMG signals were filtered with a frequency bandpass of 20–450 Hz, amplified (Delsys Bagnoli, Natick, MASS U.S.A.) then digitized at 1000 Hz (Micro 1401, Cambridge Electronic Designs, Milton, Cambridge England) and analyzed using Spike2 software (Cambridge Electronic Designs, Milton, Cambridge England).

A random starting stance, wide or tandem, was assigned. In each stance subjects stood as described for the standing body sway tests and the position of the right heel was kept unchanged by a low heel backstop that provided no foot support. To ensure ankle flexion or extension did not occur during a measure, the right ankle angle was monitored was not allowed to vary more than ± 1° from the preferred angle for the subject. To prevent subjects from holding a static position for an extended period, they alternated between stances, holding each stance two to four times. Force plate body sway measures in the primary study were not made concurrent with the reflex measures.

In both of the stance positions, the following procedure was followed. When the body position was being steadily held, an Achilles tendon tap was delivered by a silent pendulum tendon tapper, similar to that demonstrated by Mildren and coworkers to deliver reliable Achilles tendon tap forces in standing subjects (Mildren, Zaback, Adkin, Frank, & Bent, 2016). A force transducer (Bertec, Columbus, Ohio U.S.A.) in the head of the pendulum tapper recorded the strike force at a sampling frequency of 1000 Hz (Micro 1401, Cambridge Electronic Designs, Milton, Cambridge England). The tendon taps did not produce discomfort, occurred at unpredictable random intervals, and were separated by at least 15 s (Grey et al., 2008; Pierrot-Deseilligny & Mazevet, 2000).

Stretch reflex amplitude varies with static joint angle (Lin et al., 1997). Accordingly, an ankle goniometer ensured that ankle angle did not vary beyond ± 1° from the preferred angle for the subject during reflex measurements. The attached goniometer, however, has the potential to act as an ankle brace, possibly providing stance support and affecting body sway, thereby making the tandem stance less challenging than without the goniometer attached and the results having less external validity to narrow stances outside of the research setting. Additionally, the goniometer could provide additional cutaneous feedback to affect ankle proprioception (Mildren, Hare, & Bent, 2017). Accordingly, a parallel study had a first purpose to determine if the goniometer affected the standing sway of the subjects. Next, because the reflex of the soleus muscle was examined in the primary study, and this muscle functions predominately as an ankle extensor, it was also important to determine the direction of the balance challenge imposed when maintaining the tandem stance. Accordingly, the parallel study had a second purpose to examine the direction of body sway in the wide and tandem stances. For the parallel study a different group of 30 equivalent subjects (12 male, 18 female; age: 21(3) years, age range: 18–31 years) were randomly sequenced to CoP velocity standing body sway assessments in the tandem stance with and without the goniometer attached (three repeats of each) using the standing body sway test equipment described above to address the first purpose of the parallel study. Additionally, with the ankle goniometer attached to the leg and foot of the subject as described above, wide and tandem stance measures (three randomized repeats of each) were made on a force plate (AMTI, Watertown, MA U.S.A.) with Nexus 2 software (Vicon, Culver City, CA U.S.A.) analyzing at 50 Hz the medial to lateral (ML) and anterior to posterior (AP) sway, to address the second purpose of the parallel study. Procedures for these standing body sway measures were as described above. Only force plate body sway measures, and no reflex measures, were made on this second group of subjects.

2.3. Data analysis

For the standing body sway assessment, total CoP path length was determined for each trial, and averaged across the three trials

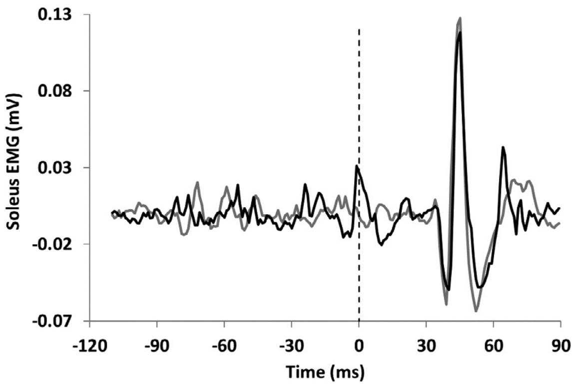

Fig. 1. Single tendon tap reflex EMG responses from a representative subject who showed a 10.7% mean decrease in tendon tap reflex amplitude in the tandem stance (black line) compared to wide stance (gray line) position. Tendon tap occurred at time zero (vertical dashed line), negative time shows soleus bEMG period.

of the same stance (High et al., 2018; Yeomans, Nelson, MacLellan, & Hondzinski, 2018). For the reflex measures, the peak-to-peak amplitude of the soleus short latency tendon tap reflex raw EMG response (Fig. 1) was measured and the baseline corrected then rectified EMG signal from 110 to 10 ms prior to each stimulus was averaged to determine the soleus and the TA muscle bEMG. The amplitude of the tendon strike force was determined. Within each subject, to ensure that a similar level of motor neuron excitability (Kearney, Lortie, & Stein, 1999; Sinkjaer et al., 1996) and tap force were compared across the stances the following matching procedure was employed. Stimuli in the wide stance were paired, if a match existed, with the stimuli in the tandem stance which had the most similar soleus and TA bEMG and tap force, with the maximum allowable difference for each pair being 6% for each of the three measures. Only these closely matched data point pairs were then used for subsequent analysis. A maximum 6% difference between stances for each of the three measures was selected because it reduced the mean difference in bEMG levels and tap forces across the stances, while resulting in at least seven stimuli per condition within a subject, a number greater or equal to the three to seven stimuli examined per condition within a subject in similar studies (Angulo-Kinzler, Mynark, & Koceja, 1998; Horslen et al., 2013; Horslen, Zaback, Inglis, Blouin, & Carpenter, 2018; Kim et al., 2013; Koceja et al., 1995; Obata, Kawashima, Akai, Nakazawa, & Ohtsuki, 2010; Shimba et al., 2010).

For each of the stance positions within a subject the tendon tap reflex amplitude, tendon strike force, and soleus and TA bEMG measures were averaged. To quantify the change in the mean amplitude of a measure across the stances, the percent change of a measure was calculated as follows: ((*measure in tandem stance* − *measure in wide stance*)/*measure in wide stance*) × 100%. Negative values, therefore, indicate a smaller measure in tandem stance.

For the parallel study, within each subject the three repeats of the total CoP path length measures with and without the goniometer were averaged. To determine the ML and AP sway in the wide and tandem stances, the CoP path length (Prieto, Myklebust, Hoffmann, Lovett, & Myklebust, 1996) of the CoP excursion in each direction was determined for each trial, and averaged for the three repeats.

2.4. Statistical analyses

Two-tailed repeated measure t-tests (Excel Microsoft Office 365, Redmond, WA U.S.A.) were used to determine if there were differences between the wide and tandem stance position for the CoP path length, tendon tap reflex amplitude, soleus and TA bEMG activities, tap force, and the AP and ML maximum CoP range. The tandem stance CoP path length with and without goniometer conditions were similarly examined. All significance levels were set at $p < 0.05$. Cohen's d values were calculated with values meeting or exceeding 0.01, 0.2, 0.5, 0.8, 1.2 and 2 indicating very small, small, medium, large, very large, and huge effects (Sawilowsky, 2009). Results are reported as mean(standard deviation). For the secondary experimental hypothesis examining the relationship between reflex modulation across the stances and standing body sway when in the tandem stance, these two variables were plotted against each other and the correlation between them calculated.

3. Results

Tendon tap reflexes could not be elicited in one subject, and only standing body sway data was obtained. There was a significant large increase in stance instability, indicated by an increased CoP path length, when in the tandem stance (Wide: 69.5(13.2) cm; tandem 106.7(30.6) cm, $p < 0.001$, Cohen's d = 1.6 large). The tandem stance produced a very small but significant increase in sway in the AP direction, determined by CoP path length (AP: Wide: 190.3(34.3) cm; tandem 196.0(31.8) cm, $p < 0.01$, Cohen's d = 0.17 very small; ML: Wide: 172.4(38.4) cm; tandem 169.3(36.5) cm, $p = 0.12$, Cohen's d = 0.08 very small). During reflex testing there was only a small, not statistically significant difference in the time spent in the two stances (Wide: 1192(274) s; tandem 1326(303) s, $p = 0.065$, Cohen's d = 0.46 small).

Table 1
Mean tendon tap (T-) reflex amplitude, background EMG levels and tendon strike force when subjects performed wide and tandem stances. Data is presented as mean (standard deviation).

	Wide stance	Tandem stance	p	Cohen's d
T-reflex (mV)	0.248 (0.124)	0.219 (0.119)	0.015*	0.24 small
Soleus bEMG (mV)	0.011 (0.006)	0.011 (0.005)	1.000	0.000 trivial
TA bEMG (mV)	0.005 (0.003)	0.005 (0.003)	#	0.000 trivial
Tendon strike force (N)	37.5 (5.6)	37.4 (5.6)	0.475	0.007 trivial

#Data for two stances was identical so p-value could not be calculated.
* Statistically significant difference between stances, $p < 0.05$.

When in the tandem stance there was a significant 11.6% decrease in mean tendon tap reflex amplitude, compared to the wide stance (Table 1, Fig. 2). In most subjects (69%) there was a smaller tendon tap reflex amplitude when in the tandem stance, compared to wide stance, illustrated by the majority of data points to the left of the vertical dashed line at abscissa 0 of Fig. 3. The differences in mean bEMG levels and tap forces across the two stances were not significant (Table 1, Fig. 2). The variability in mean tap forces (Fig. 2) reflects differences in the tapping force used to elicit the reflex across subjects, not differences within subjects across the stances. Within a subject an average of 33(19) tendon tap measures were compared across the stances (range 7–93). Only four subjects had fewer than 15 tendon tap measures per stance (n = 7, 10, 10 & 12), reducing the likelihood that if a bias in the T-reflex measurements for those four subjects occurred because the measures were made while a subject was swaying forward (Tokuno, Garland, Carpenter, Thorstensson, & Cresswell, 2008) that it would affect the overall results from the 29 subjects. Regarding the secondary experimental hypothesis, there was no relationship ($r = 0.05$, $p > 0.05$) between reflex modulation across the stances and standing body sway when in the tandem stance (Fig. 3).

The parallel examination using a second group of subjects verified that the attachment of the goniometer to the ankle did not significantly affect the standing body sway of the subjects (CoP path length: without goniometer: 102.9(17.5) cm; with goniometer 105.4(19.0) cm, p = 0.125, Cohen's d = 0.14 very small) and will not be discussed further.

4. Discussion

The present study was conducted to examine how the nervous system controls the soleus muscle short latency tendon tap reflex during an unstable stance. The novel contribution of this study was that it was the first to examine ankle muscle spindle reflexes during stances of instability levels greater than hands free standing. This allowed a test of the postulate (Chen & Zhou, 2011; Day et al., 2017; Enoka et al., 2011; Kim et al., 2013; Llewellyn et al., 1990; Pinar et al., 2010; Sefton et al., 2007; Solopova et al., 2003)

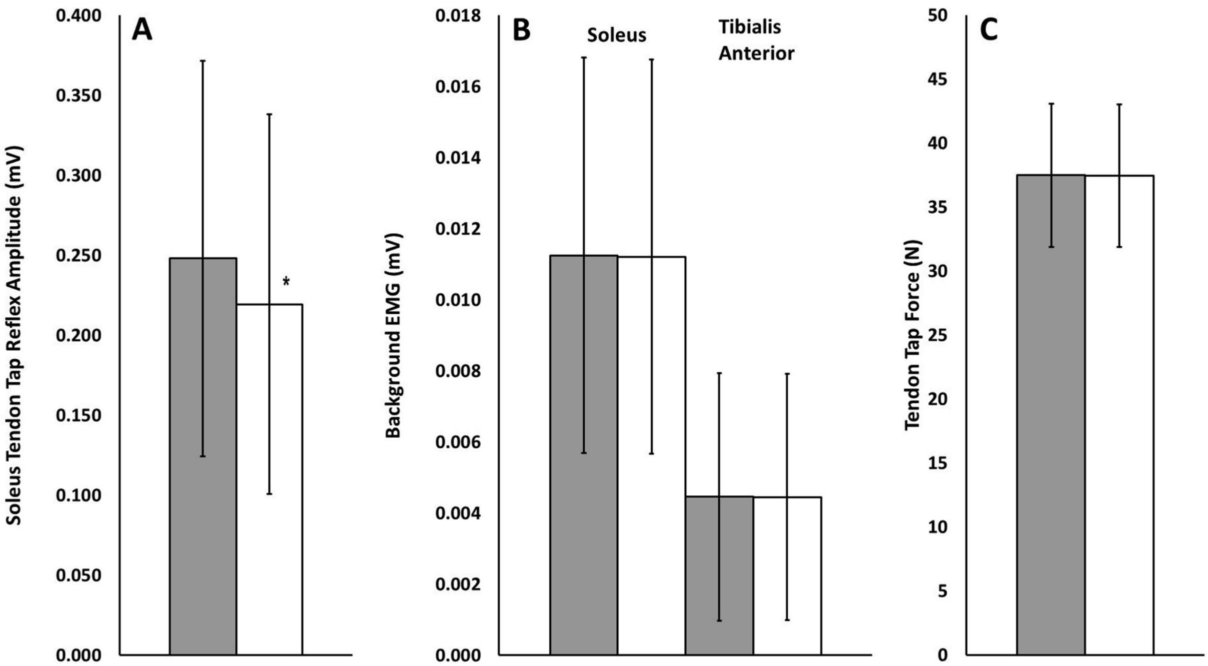

Fig. 2. Mean tendon tap reflex amplitude (A), soleus and TA background EMG activity (B) and tap force (C) when subjects performed a wide stance (shaded bar) and a tandem stance (white bar). *Significant mean difference between wide and tandem stance p = 0.015. Vertical lines indicate standard deviation.

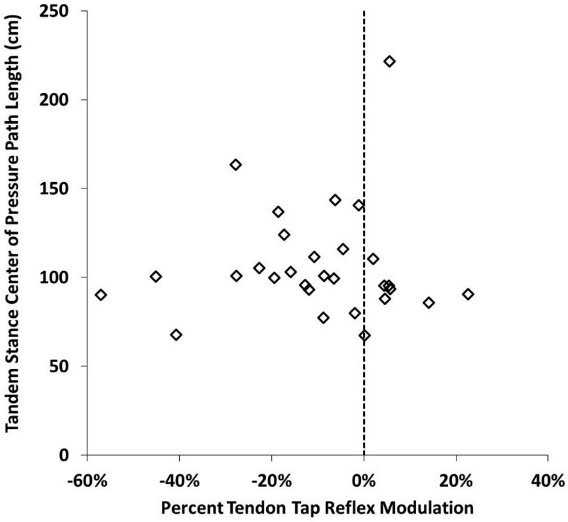

Fig. 3. The relationship between the standing body sway in the tandem stance, measured by center of pressure path length, and tendon tap reflex modulation (tandem stance tendon tap reflex amplitude expressed as percentage of wide stance tendon tap reflex amplitude). A negative reflex modulation (left of vertical dashed line) indicates a depressed reflex when in tandem stance, positive reflex modulation indicates a facilitated reflex in tandem stance. Each point represents a single subject. The correlation between center of pressure path length and tendon tap reflex modulation is r = 0.05.

that stance under reduced stability conditions may be stabilized by controlling the gain of the spindle afferent feedback loop to prevent excessive Ia activation of spinal motor neurons. This idea was supported by the mean 11.6% reduction in tendon tap reflex amplitude in the tandem stance compared to the wide stance. The tendon tap reflex amplitude reduction indicates that for spindle stretch elicited by a tendon tap during the tandem unstable conditions tested, for 69% of the subjects there was an inhibition of the Ia activity on the involved spinal motor neurons, likely by presynaptic inhibition, compared to when in wide stance. Previous studies examining the modulation of the Ia afferent signal during reduced stability stance utilized the H-reflex (Chalmers & Knutzen, 2002; Chen & Zhou, 2011; Day et al., 2017; Huang et al., 2009; Kim et al., 2013; Pinar et al., 2010; Solopova et al., 2003; Trimble & Koceja, 2001) and so excluded the possible influence of the variably sensitive muscle spindle on activity in the Ia pathway. The decreased tendon tap reflex amplitude observed parallels the down modulation of the tendon tap reflex reported for people standing quietly who increase instability by removing hand support on adjacent surfaces (Elner et al., 1976), and extends those findings showing that the down modulation of the tendon tap reflex also occurs as stance instability is further increased in the tandem position. A future study examining both hand support and width of base of support effects on standing body sway and soleus T-reflex modulation may be useful to determine the relative effects, and possible interactions, of these two influences on the control of stance stability. The present results of a reduced reflex amplitude in most subjects when in the tandem stance parallels, and verifies in standing conditions, previous work (Finley et al., 2012) finding soleus short latency stretch reflex amplitude attenuation in seated subjects during unstable ankle loads. Based on their seated results, Finley et al. (2012) theorized that in the lower limb during standing the nervous system limits the contribution of short latency stretch reflexes to joint stability because the mass of the body being supported results in a relatively long time constant of a perturbation, thus minimizing the need for a rapid reflex response. The present results of a reduced soleus reflex amplitude when in tandem stance illustrates that theorized control strategy for standing being implemented by most subjects, although the present study's tendon tap method used to stretch the soleus muscle spindles does not exactly match the ankle rotation muscle stretch utilized by Finley et al. (2012).

Not all subjects in the present study decreased tendon tap reflex amplitude when in the tandem stance. For some difficult motor tasks, or for some individuals when performing a difficult task, an increase in stretch or tendon tap reflex amplitude may be most appropriate. An attention demanding wrist extensor muscle force precision task and a hand muscle position control task facilitated the stretch or tendon tap reflex (Akazawa, Milner, & Stein, 1983; Kanosue, Akazawa, & Fujii, 1983; Nafati et al., 2004). Modeling has demonstrated that a high afferent gain is effective for minimizing external perturbations, but may contribute to instability, while a low afferent gain optimizes steadiness, and that the nervous system may select the appropriate afferent gain based on conditions (Dideriksen, Negro, & Farina, 2015). Different individuals may therefore utilize opposing strategies of increased versus decreased stretch or tendon tap reflex gain when shifting from a stable to less stable stance, as observed for the soleus H-reflex (Day et al., 2017; Kawaishi & Domen, 2016; Koceja et al., 1995). More specifically, it has been found in both young (Kawaishi & Domen, 2016) and elderly (Koceja et al., 1995) subjects, that there is a positive relationship between H-reflex amplitude modulation and measures of stability in an unstable stance, and subjects with lower levels of standing stability tended to increase the H-reflex with the less stable stance, while subjects with greater standing stability tended to decrease the H-reflex. In the present study while the majority of subjects decreased the tendon tap reflex amplitude with greater stance instability, some increased it. Regarding the secondary experimental hypothesis, there was no relationship between the tendon tap reflex modulation of the subjects with increased instability in the tandem stance and their standing body sway when in the tandem stance (Fig. 3), as previously found for the H-reflex. All subjects in the present study were healthy, young, physically active and able to perform the tandem stance well enough to stand steadily for the reflex measures. Further examination of the relationship between ankle stretch or tendon tap reflex modulation and standing body sway should include subjects demonstrating a wider range of standing body sway and/or should utilize a more challenging task for healthy young adult subjects (Pau et al., 2018).

For standing subjects, galvanic vestibular stimulation (GVS) produces enhanced body sway towards the side where the anode is located behind the ear (Britton et al., 1993). The magnitude of the response is increased if body stability is reduced, and this is directionally specific with narrowed feet placement increasing the ML sway in response to GVS (Mian & Day, 2014). Combined, data suggest that as stance stability decreases, body sway control may have a reduced reliance on muscle spindle reflexes, shown by the present results and those of Kiers, Brumagne, van Dieen, van der Wees, and Vanhees (2012) who found a reduced influence of the triceps surae spindles for posture control when standing on an unstable foam pad. In contrast, under unstable stance conditions data indicates an increased strength of effect of vestibular afferent signals on sway (Mian & Day, 2014) and of the motor cortex on the soleus and tibialis anterior muscles (Solopova et al., 2003).

4.1. Potential limitations and control of them

A tandem stance challenge was selected due to previous demonstrations that reducing the ML standing base of support results in modulation of the human soleus muscle Ia system, as reflected by the soleus H-reflex (Chalmers & Knutzen, 2002; Huang et al., 2009; Kawaishi & Domen, 2016; Llewellyn et al., 1990; Pinar et al., 2010). Further, there was similarity between the tandem stance utilized and narrow beam walking demonstrated to decrease soleus H-reflex amplitude in humans (Llewellyn et al., 1990) and enhance triceps surae spindle sensitivity in cats (Prochazka et al., 1988). The parallel study conducted verified that the reduced the base of support in the tandem stance produced a large significant increase in stance sway in the AP direction, the predominate direction of effect of the soleus muscle being tested. The lack of an increase in mean ML sway when adopting the tandem stance, and the observation that when in tandem stance the AP sway exceeded ML sway were unexpected. The same pattern of results was found when the AP and ML sway were assessed using either CoP range (Raymakers et al., 2005) or mean amplitude of the CoP oscillations (Sozzi, Honeine, Do, & Schieppati, 2013). These unanticipated effects of the tandem stance may be due to the eyes open test condition and the presence of a large closely located visual focus target. The use of a visual focus target in an illuminated room is expected to have a much greater ML stabilization effect than an AP effect (Paulus, Straube, Krafczyk, & Brandt, 1989), and has been demonstrated to reduce ML sway more than AP sway (Riach & Starkes, 1989). The large (bold font size 550) circle closely located to subjects would maximize these ML stabilization effects (Paulus et al., 1989).

Changes in reflex amplitude observed were not due to changes in alpha motor neuron excitability or reciprocal inhibition as there were no significant changes in soleus and TA muscle activity across the stances (Table 1, Fig. 2). Similarly, tap forces were unchanged (Table 1, Fig. 2). A limitation of this study is that it is possible that the activity of ankle muscles other than the soleus and the TA could have changed during the tandem stance, to affect the soleus motor neurons, and these were not measured. Additionally, stimulation of cutaneous afferents in different regions of the foot sole would change when switching between the stances examined, and this has been shown to modify ankle proprioception (Mildren & Bent, 2016), potentially influencing body sway and the T-reflex measured. Soleus tendon tap reflex amplitude can be modulated in the spinal cord during distraction, discomfort, attention changes or distant muscle contraction (Burke, McKeon, & Skuse, 1981), but these factors were not changed across the stance conditions.

The right ankle angle was monitored in both stances during measurements and was not allowed to vary more than $\pm 1^{\circ}$ from the preferred angle for the subject. This was the same as the ankle position tolerance allowed by Finley and colleagues (Finley et al., 2012), and less than the $\pm 3^{\circ}$ tolerance in the related study by Day et al. (2017). Additionally, Mildren et al. (2016) showed that while standing, even when postural sway was not reduced through CoP feedback, tendon tap reflex amplitude was consistent and reliable when utilizing a similar pendulum hammer.

The tendon tap reflex was examined in the right leg in all subjects, and the left leg was always forward. Therefore, if leg dominance could affect the results this was not controlled for. The compliance and length of the soleus muscle tendon complex was assumed to be unchanged when comparing the two stances due to no change in ankle angle and soleus bEMG, and no expected change in connective tissue properties across the stances. If there were a change in the compliance and/or length of the soleus muscle tendon complex across the stances it would influence the affect that the tendon tap forces had on stimulating the spindles.

5. Conclusions

For most subjects, and as a group mean change, there was a reduction in soleus tendon tap reflex amplitude when in the unstable tandem stance, compared to a wide stable stance. These data indicate that short latency Ia tendon tap reflex activation of homonymous motor neurons is typically reduced during the tested unstable tandem stance. Results support the idea that during an unstable stance Ia activation of motor neurons is typically reduced, thus avoiding possible instability in the reflex loop or saturating the reflex pathway and possibly interfering with descending control of the involved spinal motor neurons.

Research data for this article

The collection of the datasets used during this study were approved by the institutional Human Subjects Review Committee and by the subjects in their consent forms for use only for the purpose of this study's goals, and so are not available for use for other research questions. Given this constraint, the data are available from the corresponding author upon reasonable request.

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Declarations of interest

None.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.humov.2019.02.013.

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