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Differences in neuromuscular activity of ankle stabilizing muscles during postural disturbances: A gender-specific analysis

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ABSTRACT

The purpose was to examine gender differences in ankle stabilizing muscle activation during postural disturbances. Seventeen participants (9 females: 27 ± 2yrs., 1.69 ± 0.1 m, 63 ± 7 kg; 8 males: 29 ± 2yrs., 1.81 ± 0.1 m; 83 ± 7 kg) were included in the study. After familiarization on a split-belt-treadmill, participants walked (1 m/s) while 15 right-sided perturbations were randomly applied 200 ms after initial heel contact. Muscle activity of M. tibialis anterior (TA), peroneus longus (PL) and gastrocnemius medialis (GM) was recorded during unperturbed and perturbed walking. The root mean square (RMS; [%]) was analyzed within 200 ms after perturbation. Co-activation was quantified as ratio of antagonist (GM)/agonist (TA) EMG-RMS during unperturbed and perturbed walking. Time to onset was calculated (ms). Data were analyzed descriptively (mean ± SD) followed by three-way-ANOVA (gender/condition/muscle; $\alpha = 0.05$). Perturbed walking elicited higher EMG activity compared to normal walking for TA and PL in both genders ($p < 0.000$). RMS amplitude gender comparisons revealed an interaction between gender and condition ($F = 4.6$, $p = 0.049$) and, a triple interaction among gender, condition and muscle ($F = 4.7$, $p = 0.02$). Women presented significantly higher EMG-RMS [%] PL amplitude than men during perturbed walking (mean difference = 209.6%, 95% confidence interval = −367.0 to −52.2%, $p < 0.000$). Co-activation showed significant lower values for perturbed compared to normal walking ($p < 0.000$), without significant gender differences for both walking conditions. GM activated significantly earlier than TA and PL ($p < 0.01$) without significant differences between the muscle activation onsets of men and women ($p = 0.7$). The results reflect that activation strategies of the ankle encompassing muscles differ between genders. In provoked stumbling, higher PL EMG activity in women compared to men is present. Future studies should aim to elucidate if this specific behavior has any relationship with ankle injury occurrence between genders.

1. Introduction

Gender differences in the prevalence of lower leg injuries are frequently discussed [1–3]. The majority of papers have focused on knee injuries in athletes with females showing up to 8 times higher ACL injury prevalence rates compared to males [2,4,5]. Especially in landing, pivoting or cutting maneuvers, described as non-contact situations in soccer, handball or basketball, women are at greater risk of injury [2,6]. Anatomical, biomechanical, hormonal and neuromuscular factors have been discussed as risk factors [2,6]. Gender-specific differences in knee muscle activity during various athletic tasks have mainly been investigated to explain these factors influencing ACL injury prevalence [7,8]. An increased quadriceps and decreased hamstring activation during stance phase while running, side cutting and cross cutting, respectively, could be shown in females compared to males [7,8]. Consequently, it has been concluded that females' functional joint stability is reduced, which might explain the higher injury risk [2,6]. Hence, an association of neuromuscular activity with knee injury risk has been established [9].

Gender-specific differences involved in the incidence of ankle sprains are the subject of controversy [10–12]. Beynnon et al. [10] reported no differences in the injury rate of ankle sprains between

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males and females. In contrast, Lindenfeld et al. [12] showed a threefold higher injury risk for males compared to females. Doherty et al. [1] reported as a major finding of their systematic review and meta-analysis an incidence of ankle sprains in females up to two times higher than that of males. In contrast, no differences were found regarding the prevalence (10.6% females; 11.0% males). Nevertheless, controversies of prevalence rates between studies could be based on type of sport, mechanism (contact vs. non-contact) of injury and confounders (e.g. playing surface, shoe type etc.) analyzed. Moreover, the differences in neuromuscular activity of ankle stabilizing muscles between genders remain unclear and evidence is scarce [3,11]. In one of the only few articles focusing on gender differences in neuromuscular activity of the ankle muscles, Baur et al. [11] reported gender-specific higher pre-activation (before heel strike) amplitudes of the M. peroneus longus in women during running. In addition, Mengarelli et al. reported an overall higher occurrence of ankle-muscle co-contractions in females during walking that should be associated to a more complex muscular recruitment pattern. They conclude a need for a higher level of ankle-joint stabilization in females [13]. Indeed, these neuromuscular responses might be expected since women's inversion-eversion [14] and dorsiflexion [15,16] ankle stiffness is reduced compared to that of men.

Regardless of gender, various studies could proof high injury rates for inadequate landings, cutting and stopping movements, especially in sports with a high proportion of running loads [5,17]. Besides, these non-contact situations typically occur unexpectedly, suddenly and quickly and therefore require a strong as well as rapid response of the muscles to adequately compensate the injury mechanism. Therefore, the use of a suddenly as well as rapidly applied stumbling perturbation allows assessing the capability of the ankle muscles to respond rapidly. In addition, the compensation of unexpected lower limb perturbations is an essential mechanism for achieving the postural control needed in high-performance sports. Therefore, the analysis of the neuromuscular response of the ankle muscles methodologically requires rapidly applied loading situations. In order to present experimentally real non-contact situations, these experiments initiate a disturbance stimulus that requires a direct involuntary compensation of additive rapidly applied loads. This elucidates the differences to previously used tilt platforms or more dynamic landing or cutting manoeuvres and therefore the need for continuous movement situations. In this respect, stumbling while walking seems to be a suitable functional testing situation in assessment of ankle muscle activity. The unique technique (split-belt treadmill perturbation [18]) allows the simulation of an automated movement task combined with a high intensity perturbation. Therefore the analysis of repetitive, continuous gait cycles is possible compared to previous studies investigating landing, pivoting, or cutting manoeuvres using single trials only [18].

To investigate ankle encompassing muscle activity in non-contact situations, relevant experimental tests with unanticipated high loading are necessary. However, provoked stumbling during gait remains poorly investigated so far. Consequently, the purpose of our study was to investigate gender differences in ankle muscle activation after provoked stumbling during gait. Due to the previously documented observations regarding women's ankle stiffness [14–16] and their different neuromuscular patterns during walking [13] and running [11]. It was hypothesized that females show higher EMG amplitudes in response to the walking perturbations, especially for the main ankle stabilizer muscles such as tibialis anterior and peroneus longus.

2. Methods

Seventeen participants (9 females (f): 27 ± 2 yrs., 1.69 ± 0.07 m, 63 ± 7 kg; 8 males (m): 29 ± 2 yrs., 1.81 ± 0.07 m; 83 ± 7 kg), free of acute and chronic pain as well as recent injury at the lower extremities (e.g., no acute ankle trauma in the last 7 days and/or ACL rupture), were included in the study. All participants were physically active at least 2–3 times a week for a minimum of 60 min each session. In addition, no chronic pain at the lower extremities (e.g. chronic ankle instability), no surgery in the last 12-month at the lower extremities as well as no ligament rupture in the last 12-month were required for study participation. Moreover, acute and chronic infection, as well as limited suitability for walking, running and jumping movements as well as not being an elite athlete was set as exclusion criteria. The principal investigator assessed inclusion as well as exclusion criteria orally before inclusion into the study. Afterwards, the principal investigator informed all participants about the background, purpose and methods of the study. All participants signed their written informed consent before voluntary participation. The University's Ethical Committee gave ethical approval.

A cross-sectional study design was used to evaluate gender differences in ankle muscle activity in response to provoked perturbations, using a novel split-belt device that has been recently validated and tested for reliability [18]. The measurement protocol started with the assessment of anthropometrics. Next, participants were prepared for electromyographic (EMG) recordings. Three pairs of surface EMG-electrodes were positioned on the M. tibialis anterior (TA), M. peroneus longus (PL) and M. gastrocnemius medialis (GM) of the right leg [19]. In addition, all participants wore a customized standard (running) shoe to ensure that all participants had comparable walking conditions. Subject preparation was followed by a 5-min walking familiarization and warm-up on the treadmill at 1 m/s (Split-belt treadmill, Woodway, Weil am Rhein, Germany). During this warm-up phase, no perturbations were applied. After a 3-min resting period, the stumbling protocol began. Each subject walked for about 8.5 min at a baseline velocity of 1 m/s on the split-belt treadmill. While walking, 15 right- and 15 left-sided stumbling stimuli were randomly applied 200 ms after initial heel contact triggered by a plantar pressure insole (Pedar X, Novel, Munich, D). This ensures that participants are perturbed in the early phase of the gait cycle (weight acceptance) and single support phase bearing already full load of body weight on the foot [20]. For each perturbation, one treadmill belt was decelerated by 40 m/s^2 within 50 ms (Fig. 1) [21]. A

A. B.

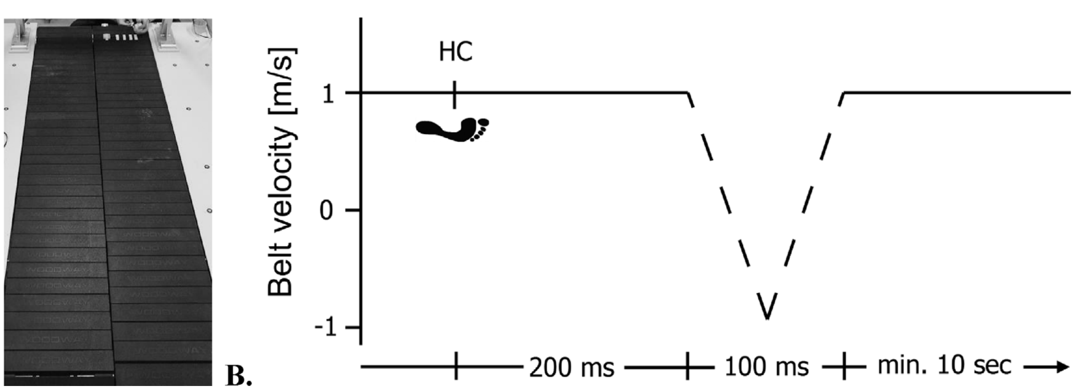

Fig 1. A. Customized Split belt treadmill with 2 separate selectable belts (Woodway). B. Treadmill perturbation characteristics (HC: initial heel contact).