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The threat of a support surface translation affects anticipatory postural control

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ABSTRACT

This study examined how postural threat in the form of a potential perturbation affects an individual's ability to perform a heel raise. Seventeen adults completed three conditions: i) low threat, where participants performed a heel raise in response to a "go" tone, ii) high threat, where participants either heard the same "go" tone, for which they performed a heel raise, or experienced a support surface translation in the medio-lateral direction that disturbed their balance, and iii) choice reaction time task, where participants either completed a heel raise in response to the same "go" tone or a toe raise in response to a lower pitched tone. For all heel raise trials, anticipatory postural adjustments (APAs) were quantified from center of pressure (COP) recordings and electromyographic (EMG) activity from the tibialis anterior (TA) and soleus (SOL). Results indicated that participants exhibited larger APAs, as reflected by the greater backward COP displacement ($p = 0.038$) and velocity ($p = 0.022$) as well as a larger TA EMG amplitude ($p = 0.045$), during the high threat condition. During the execution phase of the heel raise, an earlier ($p = 0.014$) and larger ($p = 0.041$) SOL EMG activation were observed during the high threat condition. These results contrast with previous findings of reduced APAs when the postural threat was evoked through changes in surface height. Therefore, the characteristics of the postural threat must be considered to isolate the effects of threat on anticipatory movement control.

1. Introduction

Previous studies have examined how postural threat impacts anticipatory postural adjustments (APA) when initiating voluntary movement. For example, when postural threat is induced by having individuals perform a voluntary movement towards the edge of an elevated surface, smaller APAs, as reflected by reduced tibialis anterior (TA) activation and backward center of pressure (COP) displacement, are observed during the initiation of a heel raise [1,2]. The subsequent forward COP displacement and soleus (SOL) activation, which help to arrest the body's forward movement and maintain the body's final elevated posture, are also reduced [1]. The effects of postural threat evoked through an elevated surface is consistent across tasks, with smaller APA amplitudes occurring during the performance of a leg flexion task [3,4] as well as reduced and more variable lower limb muscle activity when walking above ground level [5,6].

These threat-related adaptations may be a result of individuals adopting a strategy that minimizes body movements occurring toward the surface edge and consequently, a potential fall. This is evidenced by individuals leaning their body away from the surface edge during standing [7], as well as demonstrating a smaller forward COP displacement when performing a heel raise while standing just behind the surface edge [1]. Similarly, smaller lateral COP displacements associated with a leg flexion task occur when individuals stand with the surface edge to their side [3,4]. But since these threat-related adaptations become less prominent when the same leg flexion movement is made away from rather than toward the edge of the surface height, these results further support the notion that adaptations are dependent on the potential risk of falling [4].

Despite these previous findings, it is currently unknown whether previously observed changes in APAs at an elevated surface height are generalizable to other sources of threat.

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Therefore, this study introduced a different form of postural threat, specifically a potential medio-lateral (M-L) perturbation to the body, to examine whether this form of threat affects an individual's ability to perform a voluntary heel raise. Based on previous work [1,3], it was hypothesized that the threat of losing one's balance would lead to smaller APAs, as reflected by smaller TA activation and backward COP displacement. In turn, it was expected that the execution of the heel raise would be reduced in magnitude and velocity but increased in duration.

2. Methods

2.1. Participants

Seventeen adults (11 males; mean ± one standard deviation [SD] age of 21 ± 1 y, height of 1.72 ± 8.48 m, mass of 69.6 ± 14.4 kg) participated in this study. Individuals were excluded if they had any hearing disorders or reported any history of musculoskeletal, neurological, or orthopaedic injuries of the lower limbs that could affect their balance. Written consent was obtained from all participants prior to their involvement in the study and the university research ethics board approved all experimental procedures.

2.2. Experimental protocol

Throughout the experiment, participants stood on a force plate (OR6-7, AMTI, Watertown, MA, USA) with a stance width that was equivalent to the participant's foot length. The force plate was positioned on top of a 0.9 m long × 1.6 m wide wooden platform that was affixed to a 4.3 m linear positioning stage (H2W Technologies Inc., Valencia, CA, USA). Participants were barefoot throughout the experiment and kept their arms relaxed at their sides. Their gaze was focused on a target 2 m ahead at eye level. From this position, participants completed three experimental conditions: low threat, high threat, and choice reaction time (CRT) task. The conditions were presented in a random order, while all trials within each condition were presented in a blocked fashion. To ensure that participants were familiar with the requirements of the heel raise task, they completed an initial practice block prior to the start of the conditions. This practice block consisted of 10 heel raise trials completed under the same task constraints as the low threat condition.

During the low threat condition, an initial warning tone was presented every 10–15 s to prompt participants of an upcoming trial. After a variable 2–12 s delay, a "go" tone was presented, indicating that participants were to immediately perform a heel raise as quickly and as far forward onto their toes as possible from their initial stance using only their ankles. They maintained this new position for 3 s before returning to their original standing position. Ten trials were performed for this condition. Unsuccessful trials were repeated if participants did not hold the final posture for the required time or did not appear to achieve the farthest possible forward position.

For the high threat condition, each warning tone was followed by two possible events, presented randomly over a total of 25 trials. In five trials, after a variable 2–12 s delay the warning tone was followed by a "go" tone, for which participants completed the heel raise in the same manner as the low threat condition. Unsuccessful heel raise trials were repeated. In 20 trials, the warning tone was followed 2–12 s later by an unpredictable support surface translation in the M-L direction. This direction was chosen so that the threat occurred perpendicular to the direction of movement and any preparatory response to the perturbation would be in a different plane than the APA of the heel raise. The support surface displaced 0.25 m, with a peak velocity of 0.9 m s^{-1}, and a peak acceleration of 1.7 m s^{-2}, in either the leftward or rightward direction. Participants were not required to perform the heel raise during trials when the platform perturbation was presented; they were instructed to try to maintain their balance without stepping.

In order to account for the potentially confounding effect of having to prepare for two motor tasks in the high threat condition (i.e., heel raise vs. responding to the support surface translation), a third condition was performed that required participants to perform a similar CRT task without the threat of perturbation. In this CRT condition, 25 trials were randomly performed. In five trials, the warning tone was followed 2–12 s later by the "go" tone, to which individuals completed the heel raise in the same manner as previously described. In 20 trials, a lower pitched "go" tone was used, to which participants rapidly dorsiflexed their right foot without altering the rest of their posture.

2.3. Data collection and analyses

2.3.1. Physiological arousal

Electro-dermal activity (EDA) was recorded (EDA100C, BIOPAC Systems Inc., Goleta, Canada) from 13 of 17 participants. Surface electrodes were placed on the participant's thenar and hypothenar eminences of the non-dominant hand [8], and the EDA data were sampled at 1000 Hz (micro1401, Cambridge Electronics Design, Cambridge, UK). The average EDA during the 2 s immediately prior to the "go" tone was determined for each trial and ensemble averages were calculated for each condition.

2.3.2. Psycho-social measures

Participants reported their balance confidence, fear of falling, perceived stability, and anxiety for each condition [9]. Balance confidence was measured prior to the start of the first trial. Participants rated on a scale of 0% (no confidence) to 100% (complete confidence) how confident they were that they could maintain their balance and avoid a fall during the heel raise. Levels of fear of falling, perceived stability, and anxiety were recorded immediately after the completion of each condition. Participants rated how fearful of falling they felt when performing the balance task (0% = not at all fearful; 100% = completely fearful), how stable they felt when performing the balance task (0% = not stable at all; 100% = completely stable) and how anxious they felt throughout the entire condition (0% = felt no anxiety; 100% = felt extremely anxious).

2.3.3. Centre of pressure

Antero-posterior (A-P) COP was obtained from the force platform on which participants stood. Ground reaction force and moment signals were collected at 1000 Hz (micro1401, Cambridge Electronics Design, Cambridge, UK). For each heel raise trial, the COP onset latency was determined as the time from the "go" tone to when the A-P COP signal moved two SDs beyond the baseline COP [1]. Baseline COP was determined as the mean COP position during the 200 ms following the "warning" tone. Following COP onset, the peak backward displacement of the A-P COP was found. The time from COP onset to this peak displacement was determined as the APA duration.

The execution phase of the heel raise followed the APA and consisted of the lift off of the heel [10]. During this phase, the initial peak forward displacement of the A-P COP and the time to this peak displacement (i.e., the time from peak backward COP to the initial peak forward COP) were measured.

2.3.4. Muscle activation

Prior to surface electromyography (EMG) electrode placement, areas over the TA, SOL and the lateral femoral condyle of the right