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RESEARCH ARTICLE

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Fear of falling modifies anticipatory postural control

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Abstract This study investigated the influence of fear of falling or postural threat on the control of posture and movement during a voluntary rise to toes task for 12 healthy young adults. Postural threat was modified through alterations to the surface height at which individuals stood (low or high platform) and changes in step restriction (away from or at the edge of the platform) creating four levels of postural threat: LOW AWAY, LOW EDGE, HIGH AWAY and HIGH EDGE. To rise to the toes, an initial postural adjustment must destabilise the body so that it can be moved forward and elevated to a new position of support over the toes. Centre of pressure and centre of mass profiles, as well as tibialis anterior (TA), soleus (SO) and gastrocnemius (GA) muscle activity patterns were used to describe this behaviour. The results showed that the performance of the rise to toes task was significantly modified when positioned at the edge of the high platform. In this situation, the central nervous system reduced the magnitude and rate of the postural adjustments and subsequent voluntary movement. Although the duration of the movement was lengthened for this most threatening condition, the sequencing and relative timing of TA, SO and GA muscle activity was preserved. These changes in rise to toes behaviour were accompanied by evidence of increased physiological arousal and participant reports of decreased confidence, increased anxiety and decreased stability. Evidence of fear of falling effects on anticipatory postural control is clinically relevant as it may explain deficits in this control observed in individuals with balance disorders. For example, individuals with Parkinson's disease or cerebellar dysfunction demonstrate impaired performance on the rise to toes task as reflected in alterations of both the timing and magnitude of their anticipatory postural adjustments. Our findings suggest alterations in the magnitude of postural adjustments may be magnified by fear of falling while changes in the timing of postural adjustments may reflect underlying pathology.

Keywords Fear of falling · Postural threat · Anticipatory postural control · Centre of pressure · Centre of mass · Electromyography

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Introduction

It is well known that the central nervous system (CNS) generates postural adjustments simultaneously with or just prior to the initiation of voluntary movement (Massion 1992). The magnitude and timing of these postural adjustments is critical and depends on the physical demands associated with the movement as well as the behavioural context in which the movement is performed (see, for example, Cordo and Nashner 1982; Horak et al. 1984; Brown and Frank 1987; Lee et al. 1987; Nardone and Schieppati 1988; Aruin et al. 1998; Toussaint et al. 1998). An anticipatory postural adjustment (APA) may serve to counteract the destabilising forces that result from the movement acting to stabilise the body centre of mass (COM). Alternatively, an APA may serve to assist movement initiation by destabilising the body in the direction of the intended movement.

GOOD INTRO

In the case of rising to the toes, an APA destabilises the body COM so that it can be moved forward and elevated to a new position of support over the toes. The APA, accomplished through activation of the tibialis anterior (TA) and/or silencing of the soleus (SO) or gastrocnemius (GA), causes the centre of pressure (COP) to move backward and body COM to move forward. Subsequent activation of the SO and GA arrests the forward movement of the COM moving the body up and over the new base of support on the toes (Lipshits et al. 1981; Clement et al. 1984; Nardone and Schieppati 1988; Diener et al. 1990; Kasai and Kawai 1994). The movement up and onto the toes is compromised if this initial postural adjustment is absent, of insufficient magnitude or inappropriately timed. For example, individuals with Parkinson's disease (PD) or cerebellar dysfunction demonstrate impaired performance on the rise to toes task as reflected in alterations of the magnitude and timing of their postural adjustments (Kaneoke et al. 1989; Diener et al. 1990, 1992; Frank et al. 2000). These alterations in postural control are normally attributed to underlying physiological changes resulting directly from the disease process. However, psychological factors, such as fear of falling may act to compound the balance problem.

The need to understand fear of falling and its relationship to postural control is apparent as this fear is highly prevalent in the elderly (Murphy and Isaacs 1982; Tinetti et al. 1988, 1994; Downton and Andrews 1990; Walker and Howland 1991; Arfken et al. 1994; Vellas et al. 1997) and individuals with balance disorders (Burker et al. 1995; Yardley and Hallam 1996). Maki et al. (1991, 1994) and Krafczyk et al. (1999) demonstrated the possible confounding effects of fear of falling on the control of posture in the elderly and individuals with phobic postural vertigo, respectively. These studies have demonstrated that fear does modify strategies for the control of posture. In our previous studies on healthy young adults (Brown and Frank 1997; Carpenter et al. 1999, 2001; Adkin et al. 2000), we introduced a threat to posture by having individuals stand at different surface heights above ground level. This situation may provide a similar challenge to that experienced by an individual with a fear of falling. When threatened, participants adopted a tighter control of posture, characterised by smaller amplitude and higher frequency postural sway during quiet standing and reduced displacement and velocity of COM movement in response to a destabilising push applied to the upper back. The influence of fear or postural threat effects on anticipatory postural control has not been investigated.

The purpose of this study was to examine the influence of fear of falling or postural threat on the organisation of posture and voluntary movement during a rise to toes task in healthy young adults. In this study, fear of falling was equated with low balance confidence in the ability to perform a specific activity as described by Tinetti et al. (1990) and Powell and Myers (1995). We hypothesised that when rising to the toes under a greater threat to posture, the timing and magnitude of the APA and voluntary movement would be altered.

Materials and methods

Participants

Twelve healthy young adults (six females and six males, mean ± SD age 26.5±3.9 years) volunteered to participate in this study. Each participant completed a medical history and physical activity questionnaire. Exclusion criteria included any self-reported neurological, balance or musculoskeletal disorder. Each participant, informed of the experimental procedures, provided written consent prior to the testing session. The University of Waterloo Office of Research Ethics approved all experimental procedures.

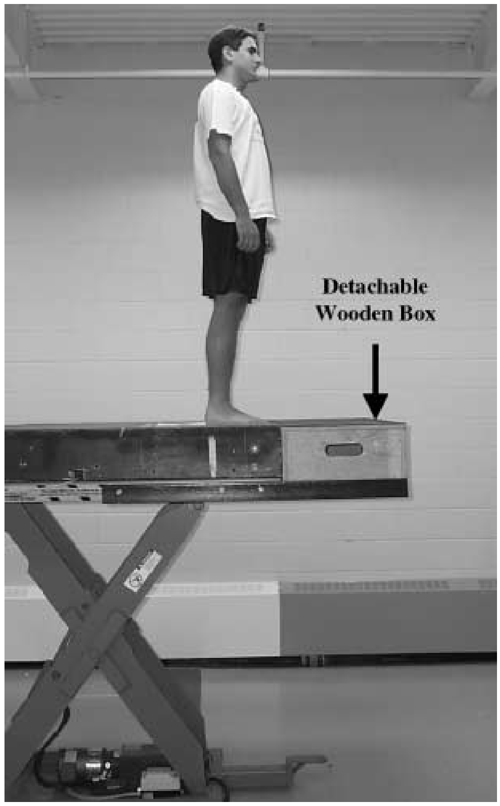

Fig. 1 View of the hydraulic platform lift used to create four levels of postural threat. Surface height was set at 0.4 m (LOW) or 1.6 m (HIGH) above ground level. Participants stood either 0.5 m away from the edge of the lift (AWAY) or at the edge of lift (EDGE) when the wooden box mounted to the lift was removed. The present view shows a participant standing on the force plate at the HIGH AWAY condition

Experimental protocol

Manipulation of postural threat

Postural threat was modified through alterations to the surface height and step restriction of the support surface on which individuals stood. Surface height was altered using a hydraulic platform lift (width 1.2 m, length 2.2 m) which could be raised to different heights above ground level (Fig. 1). A portable AMTI force plate, mounted on a planed marble base, was placed on the lift. The vertical distance from the top of the force plate to ground level was 0.4 m when the lift was completely lowered. The low surface height condition was experienced when the lift was in this position. For the high surface height condition, the lift was raised so that the vertical distance from the top of the force plate to ground level was 1.6 m. Step restriction was altered by having individuals stand with their toes at or away from the edge of the lift. For the latter condition, a wooden box (0.5 m deep) was securely mounted to the lift in front of the force plate and level with the force plate surface; this allowed one full step to recover balance if necessary (McIlroy and Maki 1993). The combination of changes in surface height and step restriction created four levels of postural threat: low surface height with no step restriction (LOW AWAY), low surface height with step restriction (LOW EDGE), high surface height with no step restriction (HIGH AWAY) and high surface height with step restriction (HIGH EDGE). Level of postural threat was presented in the same order for each participant: LOW AWAY, LOW EDGE, HIGH AWAY and HIGH EDGE. Postural threat was considered to increase from LOW AWAY to HIGH

EDGE conditions. This order of presentation prevented a more threatening condition from influencing the performance on a less threatening condition as presentation order of postural threat has been shown to influence the control of posture (Adkin et al. 2000).

Procedure

Each participant, prior to the start of the experiment, performed 20 practice rise to toes trials at ground level to remove any potential learning effect. Participants were instructed to stand quietly on the force plate with their arms at their sides and their eyes open. Participants fixated on a target located 6 m in front of them at eye level. The toes were placed at the anterior edge of the force plate and maximum stance width was equal to the participant's foot length. Foot position was traced to maintain the same initial stance position for each trial. From this initial standing position, participants were instructed to voluntarily rise to the toes as quickly as possible following a verbal cue and maintain this new position of support over the toes for 3 s. Participants were instructed to perform the task using only their ankles and to avoid extensively flexing their knees or hips or moving their arms. Five consecutive rise to toes trials were completed for each level of postural threat. Unsuccessful rise to toes trials were repeated with the frequency of unsuccessful attempts recorded. At the completion of each block of rise to toes trials, participants were seated and provided with a rest period. Participants wore a safety harness, which was tethered to the ceiling, throughout the entire testing session. The harness did not provide support to the participant during the trials unless loss of balance occurred. Participants were not allowed to test the security of the harness.

Data collection and reduction

Skin conductance

Skin conductance measures provided an estimate of physiological arousal. Skin conductance was recorded using disposable surface electrodes placed on the thenar and hypothenar eminences (Skin Conductance Coupler; Coulbourn Instruments) based on the recommendations of Fowles et al. (1981). The skin conductance signal was collected with a sampling frequency of 1,024 Hz; this raw signal was low-pass filtered at 5 Hz using a dual-pass second-order Butterworth filter. While seated at the low height, skin conductance was collected and this value reflected a baseline resting skin conductance level. For each rise to toes trial, skin conductance was averaged across the duration of the trial and expressed as a percent change from the skin conductance level observed at the initial seated condition.

Perceived confidence, stability and anxiety

For each level of postural threat, perceived confidence, stability and anxiety measures were reported by the participant. Prior to the series of rise to toes trials, participants were asked to rate their confidence in their ability to maintain balance and avoid a fall during the task. The rating scale ranged from 0% (no confidence) to 100% (complete confidence). Following each series of rise to toes trials, perceived stability and anxiety ratings were obtained. Postural stability ratings were obtained based on the example of Schieppati et al. (1999). Participants were asked to rate how stable they had felt during the series of rise to toes trials. The rating scale ranged from 0% (I did not feel stable at all) to 100% (I felt completely stable). Perceived anxiety levels were assessed using a 16-item questionnaire modified from Smith et al. (1990). Participants scored each item on the questionnaire using a 9-point scale ranging from 1 (I did not feel this at all) to 9 (I felt this extremely). Items were classified into somatic (6 items), worry (4 items) and concentration (6 items) subgroups. All 16 items were summed to generate a total score for the questionnaire and items were also

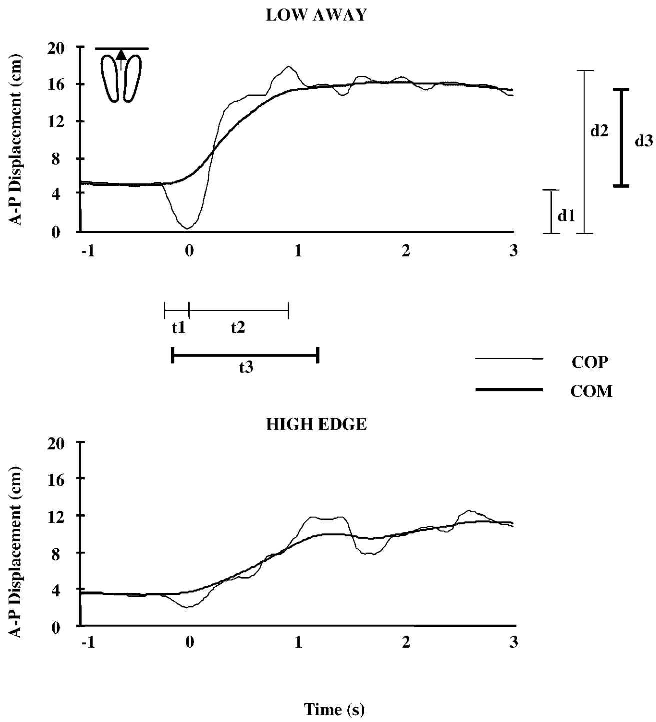

Fig. 2 Anterior-posterior (A-P) centre of pressure (COP; *light line*) and centre of mass (COM; *dark line*) profiles for LOW AWAY and HIGH EDGE conditions. For each condition, trajectories, referenced to the ankle joint (0 cm), represent the mean of five rise to toes trials for one participant. The time at which peak COP backward displacement occurred was selected as the temporal reference point for all measures. Duration of the COP anticipatory postural adjustment (APA; *t1*) and duration of forward COP (*t2*) and COM (*t3*) movement were calculated. Magnitude of the COP APA (*d1*) and magnitude of forward COP (*d2*) and COM (*d3*) movement were determined. Peak backward velocity of the COP APA, peak velocity of the forward COP movement and peak acceleration of the forward COM movement were also calculated

summed within each subgroup to examine the three different elements of the questionnaire.

Centre of pressure and centre of mass

Ground reaction force and moment of force signals were collected from the force plate with a sampling frequency of 1,024 Hz to allow calculation of COP. Participants were also instrumented with 21 infrared-emitting diodes (IREDs) providing an estimation of total body COM using the 14-segment model described by Winter et al. (1998). The IREDs were tracked with a collection frequency of 64 Hz using the OPTOTRAK motion analysis system (Northern Digital). COP and COM profiles in the anterior-posterior (A-P) direction were examined for each trial. COP data was down-sampled to 64 Hz to temporally align the COP and COM trajectories. The COP and COM signals were low-pass filtered with a cut-off frequency set at 5 Hz using a dual-pass second-order Butterworth filter.

Key COP and COM summary measures were selected to describe the rise to toes behaviour (Fig. 2). The time at which peak backward displacement of the COP trajectory occurred was selected as the temporal reference point for all COP and COM measures (i.e. set to 0 ms). The A-P COP displacement profile was divided into APA and forward movement components. The COP APA component was defined as the interval from onset of change in displacement to peak backward displacement of the COP. The onset of change in COP displacement was determined by calculating a mean baseline value over 200 ms during the quiet interval before the rise to toes was initiated and searching for the point at which the profile moved above this baseline value plus two standard deviations and remained above this value for a 50-ms interval. The COP forward movement component was defined as the interval from peak backward to peak forward displacement of the COP. The magnitude and duration for the COP APA and forward movement components were determined. Furthermore, the COP displacement profile was differentiated to obtain a COP velocity profile, and peak backward velocity for the COP APA component and peak forward velocity for the COP forward movement component were identified.

The A-P COM displacement profile was characterised by a single forward movement component. The COM forward movement component was defined as the interval from onset of change in displacement to peak forward displacement of the COM. The onset of change in COM displacement was determined with the same procedure used for COP. The magnitude and duration for the COM forward movement component were determined. The COM displacement profile was twice differentiated to obtain a COM acceleration profile, and peak forward acceleration for the COM forward movement component was identified. The number of crossings of the COM trajectory by the COP was also determined for the interval between the peak backward displacement of the COP to peak forward COM displacement to provide additional insight into the CNS control of the movement.

Electromyography

Raw electromyographic (EMG) signals were collected with disposable surface electrodes placed bilaterally on the TA, SO and medial GA muscles. The EMG signals were collected with a sampling frequency of 1,024 Hz. The raw EMG signals were rectified and low-pass filtered using a dual-pass second-order Butterworth filter. The cut-off frequency for the low-pass filter was set at 100 Hz. For each trial and muscle, muscle onset latencies were determined using the following procedure. First, a mean value was calculated over a 200-ms interval prior to any noticeable onset of muscle activity. This value, reflecting baseline or resting muscle activity level, was then subtracted from the signal. Second, a computer algorithm was utilised to select the onset of muscle activity according to several criteria. Onset of muscle activity was defined as the moment when EMG activity surpassed the established baseline muscle activity level plus two standard deviations and remained above this value for a 50-ms interval. The exact point of onset was determined by searching backward to the time at which the muscle activity moved above the baseline level. Verification of the onset latency selected by the computer algorithm was made visually; a manual selection occurred for less than 3.0% of all selections. Following the determination of the muscle onset latency, integrated EMG activity levels were calculated over a 250-ms interval from the onset of the muscle activity. The algorithm also searched for offset of muscle activity to identify any silencing of the SO or GA muscle group using the same criteria except that the muscle offset was defined as the moment when EMG activity fell below the established baseline muscle activity level plus two standard deviations. Muscle onset latencies were expressed relative to the time at peak backward COP displacement.

Statistical analysis

A two-way repeated measures analysis of variance (ANOVA) procedure was performed for the skin conductance measure and each COP, COM and EMG measure. Level of postural threat (four levels: LOW AWAY, LOW EDGE, HIGH AWAY, HIGH EDGE) and trial (five levels: 1–5) were the two factors investigated. One-way repeated measures ANOVA procedures were performed for the perceived confidence, anxiety and stability measures. Level of postural threat (four levels: LOW AWAY, LOW EDGE, HIGH AWAY, HIGH EDGE) was the factor investigated. These measures were specific to the series of rise to toes trials and thus a trial effect could not be examined. A P value of less than 0.05 was used to indicate statistical significance for all cases. Bonferroni *post hoc* comparisons were performed for any significant main effects of postural threat and trial to investigate differences between the four levels of postural threat and five levels of trial, respectively. If necessary, a logarithmic transformation was applied to dependent measures to meet normal distribution requirements for statistical analyses.

Chi-square analysis was performed to examine the frequency of unsuccessful rise to toes trials for both level of postural threat and level of trial. Correlations were performed between postural control measures, physiological arousal measures and perceived confidence, anxiety and stability measures.

Results

Postural threat effects

Skin conductance and perceived confidence, anxiety and stability

A significant main effect of postural threat was observed for the percent change in skin conductance from the initial seated condition [F(3,33)=16.16, P=0.0001] and for self-reported levels of perceived confidence [F(3,33)=19.71, P=0.0001], anxiety [F(3,33)=14.14, P=0.0001] and stability [F(3,33)=17.72, P=0.0001]. For each measure, the HIGH EDGE condition was significantly different from the LOW AWAY, LOW EDGE and HIGH AWAY conditions. For example, skin conductance values increased (change of 63.5%) and participants reported less confidence (change of 46.0%), more anxiety (change of 77.3%) and felt less stable (change of 44.0%) for the HIGH EDGE compared to LOW AWAY condition (Fig. 3).

When each subgroup of the perceived anxiety questionnaire was examined independently, somatic-related items [F(3,33)=13.11, P=0.0001], worry-related items [F(3,33)=9.17, P=0.0001] and concentration-related items [F(3,33)=7.82, P=0.0004], also showed significant main effects of postural threat. The same trends observed for the full anxiety questionnaire were also observed for each of the three subgroups.

Centre of pressure and centre of mass

COP and COM trajectories for the least threatening condition (LOW AWAY) and most threatening condition (HIGH EDGE) are presented in Fig. 2. These profiles illustrate the significant differences in COP and COM control observed for the most threatening condition.

Initial position A significant main effect of postural threat was observed for the initial position of the COP [F(3,33)=6.54, P=0.0014] and COM [F(3,33)=7.17, P=0.0008]. The initial position of both the COP and COM was moved significantly backward, further away (1.2 cm) from the edge of the platform for the HIGH EDGE condition when compared with LOW AWAY, LOW EDGE and HIGH AWAY conditions.

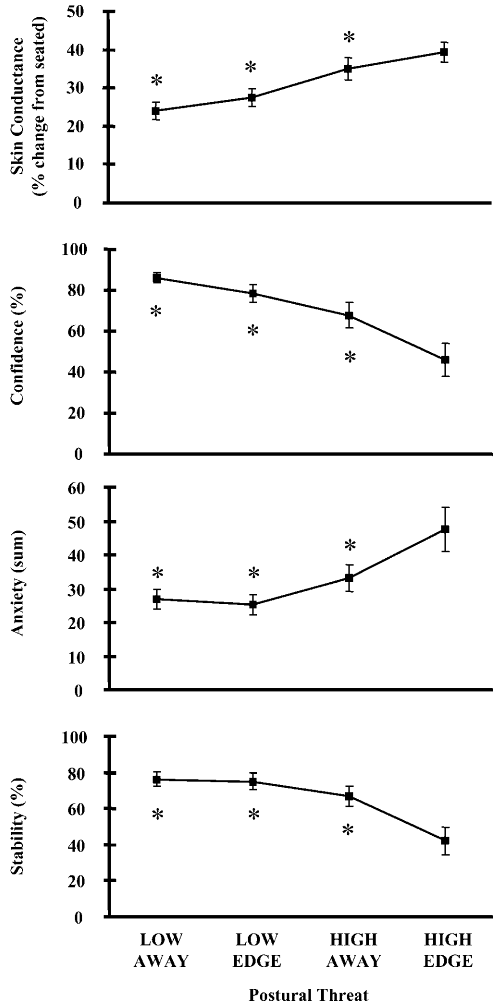

Fig. 3 Mean skin conductance values and perceived confidence, anxiety and stability ratings for LOW AWAY, LOW EDGE, HIGH AWAY and HIGH EDGE conditions. *Error bars* represent 1 standard error. * Represents different from HIGH EDGE

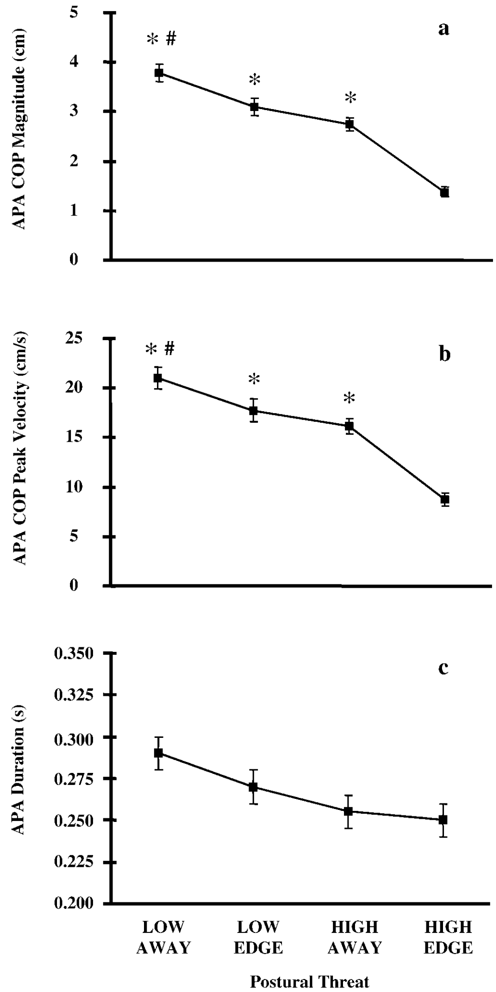

Fig. 4 Mean COP APA magnitude (**a**), peak velocity (**b**) and duration (**c**) values for LOW AWAY, LOW EDGE, HIGH AWAY and HIGH EDGE conditions. *Error bars* represent 1 standard error. * Represents different from HIGH EDGE, # represents different from HIGH AWAY

Anticipatory postural adjustment. A significant main effect of postural threat was observed for the magnitude [$F(3,33)=29.65$, $P=0.0001$] and peak velocity [$F(3,33)=28.61$, $P=0.0001$] of the COP APA. For both measures, the HIGH EDGE condition was significantly different from the LOW AWAY, LOW EDGE and HIGH AWAY conditions. The percent change decrease for the HIGH EDGE compared to LOW AWAY condition was 63.5% for COP APA magnitude and 58.5% for COP APA peak velocity (Fig. 4a, b). Furthermore, a significant difference was observed between the HIGH AWAY and LOW AWAY conditions for both magnitude and peak velocity of COP APA. The duration of the COP APA remained unchanged across level of postural threat (Fig. 4c).

Forward movement. A significant main effect of postural threat was observed for the magnitude of the forward COP movement [$F(3,33)=30.99$, $P=0.0001$] and peak velocity of forward COP movement [$F(3,33)=34.73$, $P=0.0001$]. Alterations in COM control accompanied these changes in COP control as a significant main effect of postural threat was observed for the magnitude of forward COM movement [$F(3,33)=5.08$, $P=0.0053$] and peak acceleration of the forward COM movement [$F(3,33)=30.92$, $P=0.0001$]. The magnitude and peak velocity of the forward COP movement as well as the magnitude and peak acceleration of the forward COM movement significantly decreased for the HIGH EDGE condition when compared to the three other levels of postural threat (Fig. 5a–d). The percent change decrease for the HIGH EDGE compared to LOW AWAY condition was 24.5% for magnitude and 60.3% for peak velocity of forward COP movement and 8.8% for magnitude and 56.2% for peak acceleration of forward COM movement. For forward COP magnitude and peak velocity and forward COM peak acceleration, a significant difference also was observed between the HIGH AWAY and LOW AWAY conditions.

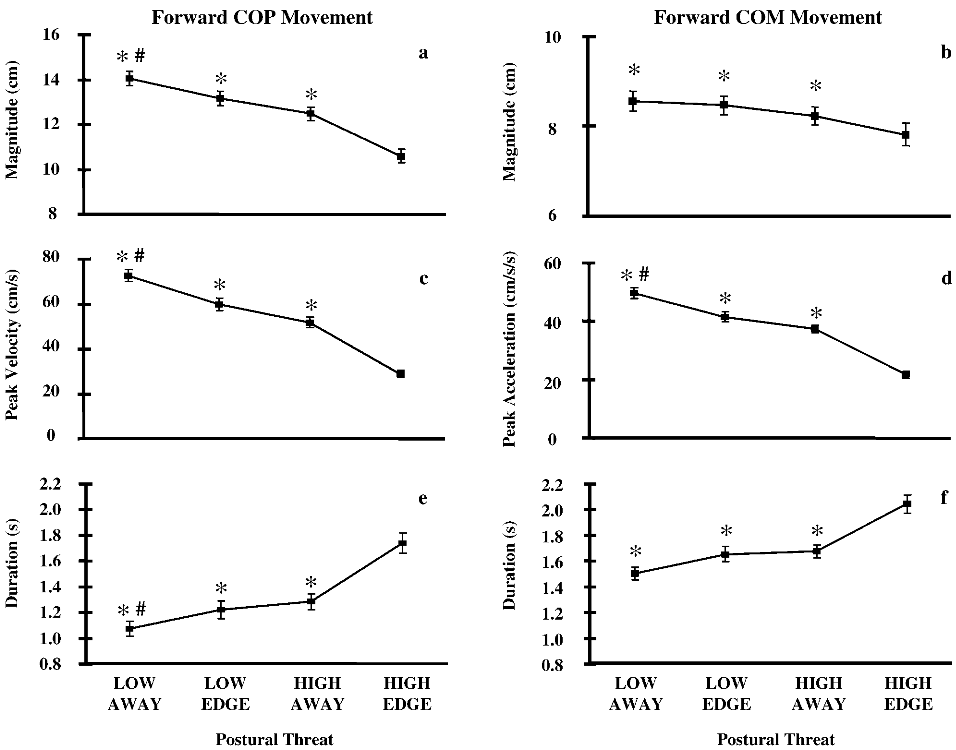

Fig. 5 Mean forward COP magnitude (**a**), peak velocity (**c**) and duration (**e**) values and mean forward COM magnitude (**b**), peak acceleration (**d**) and duration (**f**) values for LOW AWAY, LOW EDGE, HIGH AWAY and HIGH EDGE conditions. *Error bars* represent 1 standard error. * Represents different from HIGH EDGE, # represents different from HIGH AWAY

A significant main effect of postural threat was observed for the duration of the forward COP movement [F(3,33)=12.27, P=0.0001] and forward COM movement [F(3,33)=12.47, P=0.0001]. The duration of both the forward COP and COM movement was significantly lengthened for the HIGH EDGE condition when compared to the three other levels of postural threat (Fig. 5e, f). The percent change for the HIGH EDGE compared to LOW AWAY condition was 63.2% for COP and 35.8% for COM forward movement duration. Significant differences also were observed between the HIGH AWAY and LOW AWAY conditions for forward COP movement duration whereas no differences between the LOW AWAY, LOW EDGE and HIGH AWAY conditions were observed for forward COM movement duration.

Centre of pressure and centre of mass relationship. A significant main effect of postural threat was revealed for the number of crossings of the COM by the COP over the interval from peak backward COP displacement to maximum displacement of the COM [F(3,33)=5.33, P=0.0042]. The number of crossings was significantly greater for the HIGH EDGE (mean ± SE=3.9±0.3) compared to the LOW AWAY (mean ± SE=2.4±0.1) condition (Fig. 6). There were no differences in the number of crossings between the LOW AWAY, LOW EDGE and HIGH AWAY conditions.

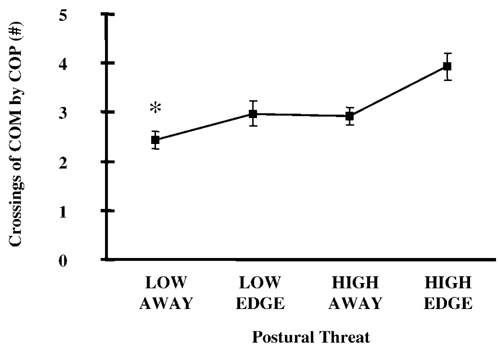

Fig. 6 Mean number of crossings of the COM by the COP for LOW AWAY, LOW EDGE, HIGH AWAY and HIGH EDGE threat conditions. *Error bars* represent 1 standard error. * Represents different from HIGH EDGE

Electromyography

Muscle onset latency and integrated muscle activity levels did not differ for right and left muscle pairs and, therefore, these were averaged and examined together. The APA required to rise to the toes can be generated either by activating the TA muscle group or reducing or silencing the activity in the SO and/or GA muscle groups. For 10 of the 12 participants, the APA involved activating the TA. For the remaining two participants, the APA involved first silencing the SO and/or GA muscles and then activating the TA. These two participants adopted this behaviour across all levels of postural threat. The

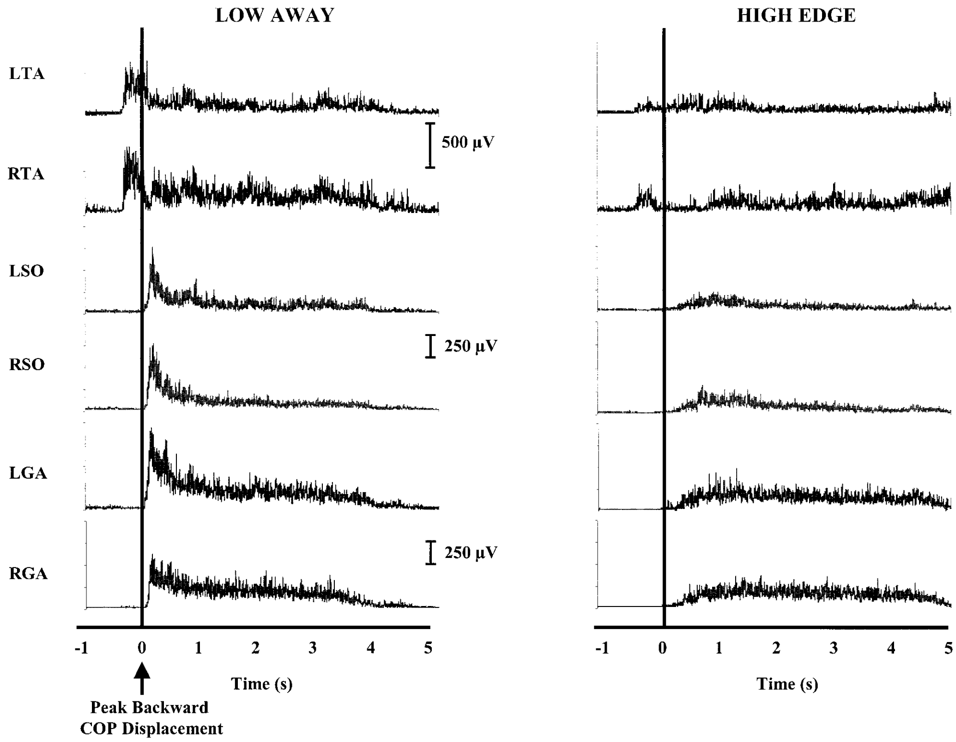

Fig. 7 Tibialis anterior (*TA*), soleus (*SO*) and gastrocnemius (*GA*) profiles for left (*L*) and right (*R*) limbs for LOW AWAY and HIGH EDGE conditions. For each condition, trajectories represent the mean of five rise to toes trials for one participant. Peak backward displacement of COP occurs at 0 ms

EMG measures for these two participants were not included in the statistical analysis.

Muscle activity level. EMG profiles for the least threatening condition (LOW AWAY) and most threatening condition (HIGH EDGE) are presented in Fig. 7. Background muscle activity levels, measured before any noticeable muscle onset, remained unchanged across all levels of postural threat. Integrated EMG activity levels, determined over a 250-ms interval after muscle onset, revealed significant main effects of postural threat for TA [$F(3,27)=6.94$, $P=0.0016$], SO [$F(3,27)=11.07$, $P=0.0001$] and GA [$F(3,27)=9.60$, $P=0.0002$]. Muscle activity levels were significantly reduced for the HIGH EDGE condition when compared to the three other levels of postural threat (Fig. 8). For example, the percent change decrease for the HIGH EDGE compared to LOW AWAY condition was 60.1% for TA, 80.2% for SO and 72.6% for GA.

Muscle onset latency. The sequence of muscle activation was consistent for all trials; TA was activated first followed by SO and GA. Muscle onset latency showed a significant main effect of postural threat for TA [$F(3,27)=3.11$, $P=0.0450$], SO [$F(3,27)=8.06$, $P=0.0008$] and GA [$F(3,27)=4.01$, $P=0.0196$]. The onset of the TA, SO and GA activity, expressed relative to peak backward displacement of the COP, was significantly delayed for the HIGH EDGE compared to the LOW AWAY condition (Fig. 9). Furthermore, SO and GA onset latencies for the HIGH EDGE condition were significantly different compared to the HIGH AWAY and LOW EDGE conditions. However, the relative timing between TA and SO onsets (mean ± SE=380±6 ms) and TA and GA onsets (mean ± SE=392±7 ms) remained consistent across all levels of postural threat.

Unsuccessful rise to toes attempts

The most threatening condition had significantly more unsuccessful rise to toes attempts compared to all other conditions [$\chi^2(3)=16.14$, $P=0.0001$]. An unsuccessful attempt occurred on 16.7% of trials in the HIGH EDGE condition compared to 1.6%, 3.3% and 8.3% in the LOW AWAY, LOW EDGE and HIGH AWAY conditions, respectively.

Trial effects

No interaction effects were observed between trial and postural threat. A trial main effect was observed for the following measures: COP APA magnitude [$F(4,44)=3.78$, $P=0.0100$] and peak velocity [$F(4,44)=3.45$, $P=0.0155$], forward COP magnitude [$F(4,44)=3.86$, $P=0.0090$], peak velocity [$F(4,44)=4.21$, $P=0.0057$] and duration [$F(4,44)=4.01$, $P=0.0074$], forward COM peak acceleration [$F(4,44)=6.95$, $P=0.0002$] and duration [$F(4,44)=5.15$, $P=0.0017$], and integrated muscle activity levels for TA [$F(4,44)=3.52$, $P=0.0172$] and SO [$F(4,44)=3.08$, $P=0.0299$]. In summary, *post hoc* comparisons revealed differences in the first trial compared to trials 2 through 5. Independent of level of postural

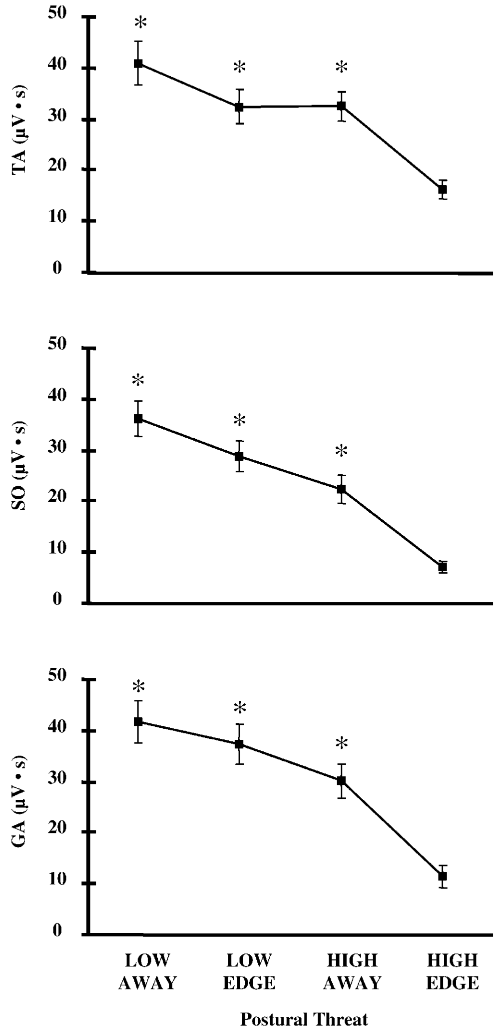

Fig. 8 Mean TA, SO and GA integrated electromyographic activity level over a 250-ms interval from muscle onset for LOW AWAY, LOW EDGE, HIGH AWAY and HIGH EDGE conditions. *Error bars* represent 1 standard error. * Represents different from HIGH EDGE

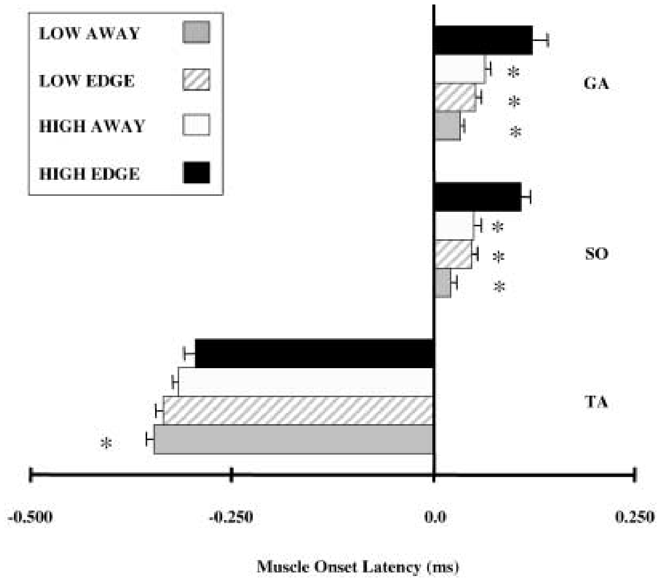

Fig. 9 Mean TA, SO and GA muscle onset latencies for LOW AWAY, LOW EDGE, HIGH AWAY and HIGH EDGE conditions. Muscle onset latencies are expressed relative to peak backward displacement of COP (at 0 ms). *Error bars* represent 1 standard error. * Represents different from HIGH EDGE

threat, the first trial was characterised by reduced magnitude and velocity of the COP APA, reduced magnitude, velocity and increased duration of the forward COP movement and reduced acceleration and increased duration of the forward COM movement. Reduced muscle activity levels for TA and SO were also observed for the first trial. Furthermore, the first trial also was associated with more unsuccessful rise to toes attempts compared to all other trials [$\chi^2(4)=37.95$, $P=0.0001$]. Unsuccessful attempts occurred on 27.0% of first trials compared to 12.5% of second trials and 0% for trials 3, 4 or 5.

Discussion

The task of rising to the toes requires an initial backward COP displacement, achieved primarily by TA activation, to allow the body COM to fall forward. This initial postural adjustment is followed by a forward COP displacement, achieved by SO and GA activation and reduced TA activation, to arrest the forward movement of the body COM and move it upwards and over the toes (Lipshits et al. 1981; Clement et al. 1984; Nardone and Schieppati 1988; Diener et al. 1990; Kasai and Kawai 1994). A significant threat to posture, rising to the toes at the edge of a high platform, modified elements of this behaviour.

Postural threat produced an anticipatory backward shift of the initial body position away from the platform edge

The initial position of the COP and COM was moved further back away from the edge of the platform for the most threatening condition, rising to the toes at the edge of the high platform. Similar shifts in position away from the edge of a high platform have been observed during quiet standing (Carpenter et al. 1999, 2001; Adkin et al. 2000) and in anticipation of a forward push applied to the upper back (Brown and Frank 1997). These changes suggest the CNS selected a safer starting position further from the platform edge to reduce the chances of the COM moving close to or over the edge of the platform. There is evidence to suggest that voluntarily leaning forward or backward prior to rising to the toes can influence the timing and magnitude of postural adjustments (Diener et al. 1990).

Postural threat reduced the magnitude and rate of postural adjustments and voluntary movement

A significant threat to posture modified the magnitude and rate of CNS control of the rise to toes task. These modifications appeared in both the anticipatory postural control and voluntary movement components of the task. When participants performed the task at the edge of the high platform, the CNS adopted a conservative strategy reducing the magnitude of the postural adjustments and thus their potential destabilising effects in the direction of the movement. Aruin et al. (1998) have shown that in conditions of postural instability the CNS reduces the magnitude of APAs to limit the potential destabilising effects from the APAs themselves; this is especially evident when the destabilising effects of the task and postural adjustments are in the same direction. In the case of rising to the toes at the edge of the high platform, the primary danger is the possibility of loss of balance in the forward direction toward the platform edge. A larger and more forceful APA would cause a greater acceleration and displacement of the COM in the forward direction. If this forward movement of the COM is not adequately arrested, loss of balance may occur and the participant may fall toward the edge of the platform. The consequences associated with a large and forceful APA may be especially extreme for this most threatening condition as there is no option for stepping to recover balance. Reducing the rate and magnitude of the APA will allow the movement of the COM to be reduced and slowed with the final position achieved by the COM being further away from the edge of the platform. If the APA is of insufficient magnitude to destabilise the COM forward or the forward COP displacement is of insufficient magnitude to arrest the forward COM movement and move it upward, the CNS can maintain balance by simply returning to the initial support position. A return to the initial support position was observed in individuals with cerebellar dysfunction when the COM was not shifted sufficiently forward due to absent or reduced APAs (Diener et al. 1990, 1992).

Postural threat lengthened the duration of voluntary movement, but did not influence the relative timing of the postural adjustments and voluntary movement

A significant threat to posture modified the duration of the rise to toes task. When rising to the toes at the edge of the high platform, the CNS increased the time taken to move the body COM to a new position of support over the toes. This was accomplished by extending the duration of the voluntary movement component and not the anticipatory postural control component of the task. Although the movement was performed more slowly in this situation, the relative timing of the lower leg muscle activation patterns (for example, difference in timing from TA onset to SO onset or TA onset to GA onset) generating the initial postural adjustment and subsequent voluntary movement was not influenced by postural threat. Critical to the performance of the task, alterations in the relative timing of muscle activation patterns may have produced greater instability in the forward direction. The increase in duration of the voluntary movement component of the task could be related to the reduction in the rate and magnitude of the postural adjustments. The increased number of crossings of the COM by the COP could also explain the prolonged duration of the voluntary movement component. This strategy would allow the CNS to more closely monitor the forward movement of the body COM as it moved to its new position of support up and over the toes.

Alterations in postural control strategy provided a greater margin of safety but compromised successful completion of the task

As discussed, the CNS adopted a cautious strategy when performing the rise to toes task at the edge of the high platform. This strategy provided a greater margin of safety protecting against a fall in the direction towards the edge of the platform but also compromised the successful completion of the rise to toes task. For example, the magnitude of the APA was reduced when performing the rise to toes task at the edge of the high platform. However, an APA of insufficient magnitude could prevent the rise to toes task from being successfully completed as insufficient torque is generated to destabilise the body COM in the forward direction. Absent or reduced APAs for individuals with PD or cerebellar dysfunction have been shown to compromise the rise to toes task (Diener et al. 1990, 1992; Frank et al. 2000). Changes in postural control strategy when rising to the toes at the edge of the high platform resulted in a greater frequency of unsuccessful attempts and participant reports of decreased stability. The CNS demonstrated increased caution in our previous studies examining the influence of postural threat on the control of quiet stance (Carpenter et al. 1999, 2001; Adkin et al. 2000) and strategies for postural recovery (Brown and Frank 1997). When threatened, participants adopted a tighter control of posture, characterised by smaller amplitude and higher frequency postural sway during quiet standing and reduced displacement and velocity of COM movement in response to a destabilising push applied to the upper back. Thus, it appears that the CNS will employ a more cautious strategy to ensure safety during voluntary movement, even one that may place the completion of the movement at risk.

Increased physiological arousal and perceptions of decreased confidence and increased anxiety were associated with postural control changes observed on the rise to toes task

Increased physiological arousal and perceptions of decreased confidence and increased anxiety were associated with changes in anticipatory postural control when performing the rise to toes task at the edge of the high platform. Significant but moderate correlations between postural control, physiological arousal and anxiety measures were observed. For example, COM peak acceleration was correlated with physiological arousal (r=0.46) and perceived anxiety (r=0.51) and APA peak velocity was correlated with physiological arousal (r=0.42) and perceived anxiety (r=0.52). Previous research has suggested that arousal and anxiety may act as potential modulators of postural control. For example, Maki and McIlroy (1996) observed that when healthy young adults attended to a cognitive task, physiological arousal was increased. The increase in arousal was associated with changes in postural control including leaning further forward and increased activity of the TA. Lepicard et al. (2000) demonstrated that the postural behaviour of anxious and non-anxious strains of mice differed when postural control was challenged; anxious mice had a greater number of falls and were less stable as reflected by trunk and tail positions compared to non-anxious mice. The converging evidence from a number of different sources provided in this study supports this view.

Fear of falling may contribute to changes observed in rise to toes behaviour for individuals with balance disorders

The co-ordination of the rise to toes task has been examined for individuals with PD (Kaneoke et al. 1989; Diener et al. 1990; Frank et al. 2000) and cerebellar disorders (Diener et al. 1990, 1992). The alterations in rise to toes behaviour in healthy young adults when significantly threatened share both similarities and differences from those reported for individuals with balance problems. When rising to the toes at the edge of the high platform, the rate and magnitude of the postural adjustments and voluntary movement was reduced, the timing of the voluntary movement was lengthened but the relative timing of posture and voluntary movement events was preserved. In PD patients, the magnitude of the postural adjustments and voluntary movement also are reduced. However, instead of a general slowing in the overall pattern of behaviour, actual disruptions in the relative timing of the components of the behaviour are observed (Kaneoke et al. 1989; Frank et al. 2000). Similar alterations in magnitude, in some cases APAs were absent, are observed for cerebellar patients (Diener et al. 1992). Furthermore, the relative timing of the posture and voluntary movement events is disrupted and quite variable for individuals with cerebellar disorders (Diener et al. 1990, 1992). Our findings suggest that alterations in the relative timing of the muscle activity may reflect underlying pathology while alterations in the magnitude of the postural adjustments and voluntary movement may be magnified by fear of falling. Thus, psychological factors such as fear of falling may play a role in modifying postural control during voluntary movement and must be considered when diagnosing and treating individuals with balance disorders.

Conclusion

Physiological variables (for example, deterioration of the balance control system) and/or psychological factors (for example, fear) may lead to alterations to strategies for postural control in older adults and patients with balance disorders. The results of this study show that postural threat or fear of falling does influence anticipatory postural control and voluntary movement when rising to the toes. Other tasks, such as step initiation, which require precise coordination between posture and movement components, have been investigated in patient populations (Burleigh-Jacobs et al. 1997), and these tasks may also be influenced by fear of falling. Thus, it is critical to identify both psychological and physiological influences on postural control when assessing individuals with balance disorders or managing elderly individuals at risk for falls.

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