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Conscious motor control impairs attentional processing efficiency during precision stepping

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ABSTRACT

Background: Current evidence suggests that fall-related anxiety can impair attentional processing efficiency during gait in both young and older adults, reducing the cognitive resources available for carrying out concurrent tasks (i.e., holding a conversation whilst walking or planning the safest route for navigation).
Research question: It has been suggested that fall-related anxiety may impair processing efficiency by directing attention 'internally', towards consciously controlling and monitoring movement. The present study aimed to evaluate this interpretation.
Methods: Fifteen healthy young adults performed a precision stepping task during both single- and dual-task (completing the stepping task while simultaneously performing an arithmetic task), under three conditions: (1) Baseline; (2) Threat (walking on a platform raised 1.1 m above ground), and; (3) Internal focus of attention (cues/instructions to direct attention towards movement processing).
Results: We observed significantly greater cognitive dual-task costs (i.e., poorer performance on the arithmetic task) during Threat compared to Baseline, with the greatest costs observed in individuals reporting the highest levels of Threat-induced conscious motor processing. Significantly greater cognitive dual-task costs were also observed during the Internal condition, confirming the assumption that consciously attending to movement reduces cognitive resources available for carrying out a secondary task during gait. These results were accompanied with significantly poorer stepping accuracy in dual-task trials during both Threat and Internal.
Significance: These findings support previous attempts to rationalise attentional processing inefficiencies observed in anxious walkers as being a consequence of an anxiety-induced internal focus of attention.

1. Introduction

It is widely accepted that the control of posture and gait requires cognitive input [1]. Much in the same way that anxiety can disrupt attentional processing, and subsequent performance, on other tasks requiring cognitive input (such as analogical problem solving) [2,3], research demonstrates that fall-related anxiety can compromise attentional processing efficiency during gait in both young [4] and older adults [4,5]. These inefficiencies can reduce the cognitive resources available for carrying out concurrent processes necessary for safe locomotion, such as feedforward movement planning [6].

Fall-related anxiety may impair processing efficiency by virtue of walkers allocating attention 'internally' towards movement-specific processes [4]. A causal relationship between fall-related anxiety and increased conscious movement processing has been documented in both young adults standing at height [7–9] and older adults when walking [10]. Cross-sectional research also implicates an internal focus as increasing attentional demands of walking [10,11], subsequently reducing cognitive resources available for carrying out concurrent processes. However, a causal relationship between the adoption of an internal focus and compromised attentional processing efficiency during gait is yet to be evaluated.

In the current study we aimed to investigate whether fall-related anxiety can compromise attentional processing efficiency during gait, as a consequence of walkers allocating attention towards movement-specific processes. To achieve this aim, we sought to experimentally induce both fall-related anxiety and conscious movement processing (independent of anxiety) and answer whether an internal focus of attention can impair attentional processing efficiency during gait in a manner similar to anxiety. Young adults performed a precision stepping task during both single- and dual-task, under three conditions: Baseline; Threat, and; Internal focus of attention. We predicted that: (1) Attentional processing efficiency would be impaired during Threat (indicated by greater cognitive dual-task costs); (2) These inefficiencies

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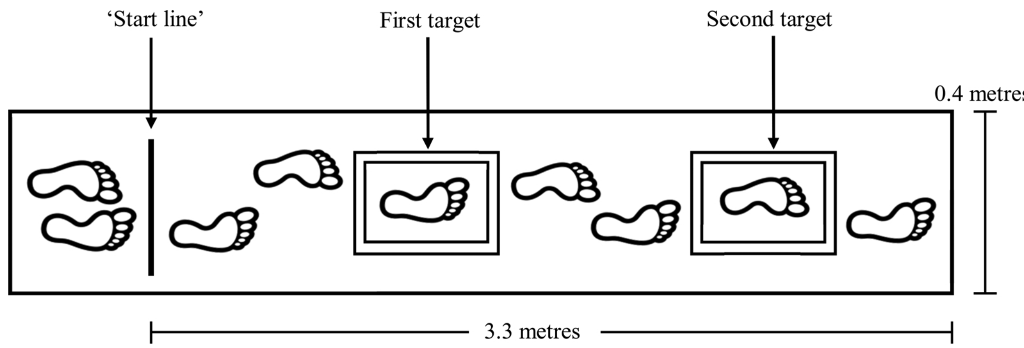

Fig. 1. Schematic diagram of the walkway and precision stepping task. The foam targets had a border width and height of 4 cm (i.e., the foam border was 4 cm wide and raised 4 cm from the walkway). The inside area of the target was 19 cm × 41.5 cm (width and length, respectively).

would be associated with greater internal focus, with the greatest costs observed in individuals reporting the highest levels of conscious movement control, and; (3) Significant processing inefficiencies would also be observed when manipulating attentional focus during the Internal condition (independent of anxiety).

2. Methods

2.1. Participants

Fifteen young adults (male/female: 8/7; mean ± SD age: 25.47 ± 2.42 years) were recruited from postgraduate courses at the lead institution. Inclusion criteria required participants to be free from any musculoskeletal, visual, auditory or speech problems. Ethical approval was obtained by the local institutional ethics committee.

2.2. Procedure

Participants walked at a self-determined pace along a wooden walkway and stepped into two foam targets (see Fig. 1) comprising raised borders (border width and height = 4 cm). The inside area of the target was 19 cm × 41.5 cm (width × length). Participants were instructed to "step into the middle of the target, placing the mid-foot marker (see Section 2.4) as close to the centre of the target as possible". Participants were permitted to step into each target with whichever foot they wished. At the start of each trial, participants stood behind a 'start line' and began walking upon an auditory 'go' tone.

Participants completed walks under three conditions: Baseline; Threat, and; Internal. Baseline involved participants completing the protocol at ground level. Threat involved participants completing the protocol while the walkway was elevated 1.1 m above ground, in the absence of a safety harness. Internal required participants to complete the protocol at ground level, while focusing their attention internally towards movement. To achieve this, participants were informed that after each trial in this condition, they would be asked a question relating to their movement. These questions were comparable to those used previously to determine 'internal awareness' [10,12] and were designed to encourage the adoption of an internal focus throughout the duration of the trial. Examples included: "What foot did you step into of the first/second target with?" and "How many steps did you take to complete the trial?" Participants were 'informed' that any trials in which they answered incorrectly would be repeated. While this deception was used to ensure engagement with the manipulation, response accuracy was recorded. Four participants provided an incorrect answer for 1 trial, respectively.

Participants completed 10 trials per condition, split across two 5-trial blocks. The presentation order of conditions was randomised, however participants only ever completed 5 trials in one condition, before being presented with a different condition. Target locations were rearranged after every block to prevent familiarisation. Targets could appear in two randomised locations (first target: either 100 cm or 110 cm from the start line; second target: either 190 cm or 200 cm from the start line).

Trials were completed under both Single-task and Dual-task conditions. Dual-task consisted of walking while concurrently subtracting in 7's from a randomised number between 70 and 90. Participants were presented with the starting number directly prior to the 'go' tone, following which they began to walk and subtract out loud. Participants were instructed to allocate equal attention towards both the walking and arithmetic task [11,13,14]. For each condition, participants completed five Single-task and five Dual-task trials, the order of which was randomised across each condition (each 5-trial block contained a randomised combination of Single- and Dual-task trials).

2.3. Self-reported state psychological measures

Participants rated their fear of falling and state movement-specific reinvestment (as a measure of conscious movement processing) after each block of 5-trials. To assess fear of falling, participants were asked: "Using the following scale, please rate how fearful of falling you felt during the past five trials" [8]. This scale ranged from 0% (not at all fearful) to 100% (completely fearful). State movement-specific reinvestment was measured using a shortened version of the Movement Specific Reinvestment Scale (MSRS) [15]. This 4-item questionnaire consisted of two 2-item subscales: conscious motor processing, i.e., 'movement control' (state-CMP; e.g., "I am always trying to think about my movements when I am doing this task") and movement self-consciousness, i.e., 'movement monitoring' (state-MSC; e.g., "I am concerned about my style of moving when I am doing this task"). Items were rated on a 6-point Likert scale (1 = *strongly disagree*; 6 = *strongly agree*). A shortened 4-item version of the MSRS has been used previously by Young et al. [10].

2.4. Attentional processing (dual-task assessments)

To quantify participants' ability to execute two tasks concurrently, we calculated dual-task costs (DTCs) according to the customary formula [16]:

Cognitive DTC (%) = 100 * (single-task score − dual-task score)/single-task score

Motor DTC (%) = 100 * (dual-task score − single-task score)/single-task score

Thus, higher DTCs reflect decreased performance under dual-task. Raw performance values are presented in Table 1.

2.4.1. Cognitive DTCs

Cognitive performance was defined as the number of correct arithmetic calculations verbalised. Dual-task scores were calculated

Table 1
Raw mean ± SD single- and dual-task values.

	Single-task Performance			Dual-task Performance		
	Baseline	Threat	Internal	Baseline	Threat	Internal
Cognitive Task (no. correct)[a]	2.29 ± 0.99	3.00 ± 1.11	2.91 ± 1.41	1.45 ± 0.51	1.45 ± 0.49	1.32 ± 0.75
AP Stepping Accuracy (mm)	30.62 ± 15.46	27.93 ± 15.79	27.43 ± 11.70	30.80 ± 16.18	30.68 ± 16.81	27.36 ± 12.84
ML Stepping Accuracy (mm)	16.04 ± 7.27	15.25 ± 9.60	17.45 ± 7.11	17.82 ± 10.09	18.79 ± 12.19	20.09 ± 7.34
Gait Speed (m/s)	0.69 ± 0.18	0.65 ± 0.19	0.63 ± 0.17	0.59 ± 0.19	0.58 ± 0.18	0.56 ± 0.17

[a] Note, that while single-task performance on the Cognitive Task was calculated during a 30-s period of arithmetic calculation (completed while seated), single-task values were extracted for a time-period proportional to the participants' mean Dual-task trial length for that condition (i.e., if a participant completed Dual-task Threat trials in 9-s, then single-task performance was calculated for the first 9-s while seated). Consequently, the time period during which participants performed the arithmetic task was proportionate within (i.e., proportionate for single- and dual-task within that condition), but not between, experimental conditions. As such, between-condition comparisons are performed on DTCs, rather than raw values.

during trials where participants performed the cognitive task while walking ('Dual-task'). Single-task scores were calculated while participants performed the cognitive task from a seated position ('Single-task'). During Single-task, participants were given 30 s to subtract as many times as possible in 7's from a randomised number. The number of correct calculations verbalised during Dual-task trials (until participants reached the end of the walkway) were then compared to those verbalised during a proportional period of time during Single-task. Separate single- and dual-task scores (and subsequent DTCs) were calculated for Baseline, Threat and Internal.

2.4.2. Motor DTCs

Two separate motor variables were calculated: (1) Stepping accuracy (mm) in the first target, for both anterior-posterior (AP) and medial-lateral (ML) directions, and (2) Gait speed (m/s). Stepping accuracy was calculated using reflective markers placed on the heel, toe (second metatarsal) and mid-foot (mid-point between the heel and second metatarsal) of both feet. The motor task featured two targets, rather than one, as previous research suggests that anxiety may only influence stepping accuracy (into the first target) when two or more stepping constraints are present [17]. Stepping accuracy was evaluated for the first target only to allow us to place our results within the context of previous research [17–20]. Kinematic data were collected at 100 Hz using a Vicon motion capture system (Oxford Metrics, England). Kinematic data were passed through a low-pass butterworth filter with a cut-off frequency of 5 Hz and analysed using custom algorithms in MATLAB 7.11 (MathWorks, Natick, MA). Stepping accuracy was calculated by subtracting the AP and ML co-ordinate of the mid-foot marker from that of the centre of the target [21]; with higher values representing greater stepping error. Gait speed was calculated until heel contact (calculated as the maximum vertical acceleration of the heel marker [21]) into the first target. Single-task performance was calculated during trials of Single-task walking (no cognitive dual-task), while dual-task scores were calculated during trials where participants performed the cognitive task while walking ('Dual-task'). Separate single- and dual-task scores (and subsequent DTCs) were calculated for Baseline, Threat and Internal.

2.5. Statistical analysis

Separate repeated-measures ANOVAs (effect size reported as partial eta squared; Bonferonni post-hoc tests used to follow up statistically significant results) were used to investigate the effect of Condition on self-reported state psychological measures (fear of falling, state-CMP and state-MSC) and cognitive DTCs. Separate paired-samples *t*-tests were then used for each condition to determine whether any cognitive DTCs were significant, when compared to zero (i.e., to determine whether performance significantly declined during Dual-task conditions) [11,16]. Effect size is reported as Cohen's *d*.

Separate Friedman tests were used to investigate the effect of Condition on motor DTCs (AP and ML stepping accuracy, and gait speed). The use of a non-parametric test was deemed necessary as data were non-normally distributed. Any significant main effects were followed up by separate Wilcoxin tests (Bonferonni corrected to 0.017). Due to difficulties associated with calculating effect size for Friedman tests, effect sizes are calculated (as $r = Z/\sqrt{N}$) instead for any Wilcoxin test follow-ups [22]. Separate Wilcoxin tests/paired-samples *t*-tests were then used for each variable to determine whether any motor DTCs were significant, when compared to zero (effect sizes calculated as either Cohen's *d* or $r = Z/\sqrt{N}$) [11,16].

Separate bivariate correlations were used to explore possible relationships between each self-reported state psychological measure (fear of falling, state-CMP and state-MSC) during Threat and both cognitive and motor DTCs during this condition. To investigate the potential confounding influence of between-condition differences in gait speed, motor DTCs for gait speed were also correlated with cognitive and stepping accuracy DTCs for each respective Condition. Only significant correlations are reported (alpha set *a priori* at 0.05).

3. Results

3.1. Self-reported state psychological measures

There was a significant effect of Condition on fear of falling ($F(1.04,14.49) = 19.49$, $p < 0.001$, $\eta p^2 = 0.58$). Participants reported significantly greater fear of falling during Threat ($M = 34.33\%$, $SD = 28.84$), compared to both Baseline ($M = 5.33\%$, $SD = 5.50$, $p = 0.002$) and Internal ($M = 7.67\%$, $SD = 7.99$, $p = 0.002$).

There was also a significant effect of Condition on state-CMP ($F(2,28) = 6.31$, $p = 0.005$, $\eta p^2 = 0.31$). Compared to Baseline ($M = 7.40$, $SD = 2.58$), participants reported significantly greater state-CMP during both Threat ($M = 9.03$, $SD = 2.77$, $p = 0.031$) and Internal ($M = 9.60$, $SD = 1.39$, $p = 0.021$). There was no significant effect of Condition on state-MSC (*Baseline* $M = 6.13$, $SD = 2.17$; *Threat* $M = 6.57$, $SD = 2.85$; *Internal* $M = 6.93$, $SD = 2.57$, $F(2,28) = 0.84$, $p = 0.44$, $\eta p^2 = 0.06$).

3.2. Attentional processing (DTCs)

There was a significant effect of Condition on cognitive DTCs ($F(1.04,14.49) = 7.76$, $p = 0.002$, $\eta p^2 = 0.36$). Post-hoc tests revealed significantly greater cognitive DTCs during both Threat ($p = 0.028$) and Internal ($p = 0.011$), compared to Baseline (Fig. 2). While significantly greater DTCs were observed for these two conditions, significant cognitive DTCs (significant decrease in performance during Dual- compared to Single-task) were observed for all 3 conditions: Baseline ($t(14) = 6.19$, $p < 0.001$, $d = 2.26$), Threat ($t(14) = 13.07$, $p < 0.001$, $d = 4.77$) and Internal ($t(14) = 8.14$, $p < 0.001$, $d = 2.97$) (Fig. 2).

There was no significant effect of Condition on motor DTCs for either AP ($\chi^2(2) = 0.13$, $p = 0.94$) or ML stepping accuracy

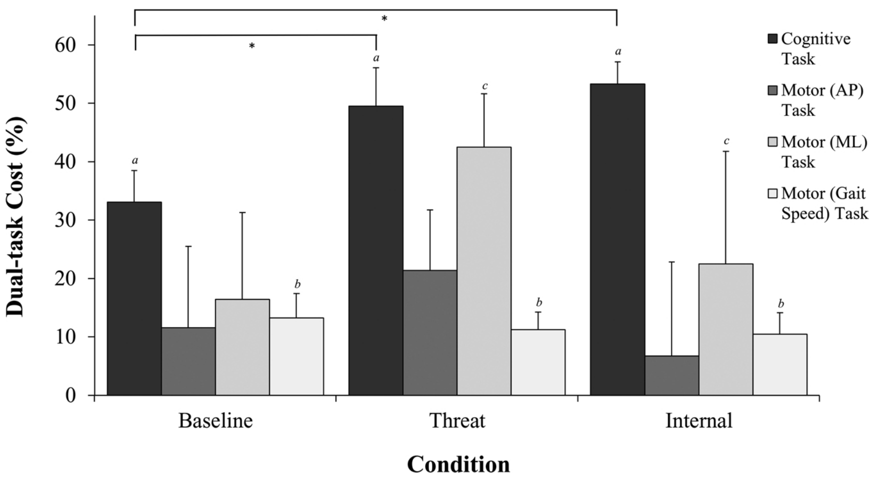

Fig. 2. Dual-task costs (as a percentage decrease in performance during Dual- compared to Single-task) (mean ± standard error of the mean), *$p < 0.05$; [a]dual-task cost significant to $p < 0.001$ (i.e., a significant decrease in performance during Dual- compared to Single-task), [b]dual-task cost significant to $p < 0.01$, [c]dual-task cost significant to $p < 0.05$.

($\chi^2(2) = 1.20$, $p = 0.55$), or gait speed ($\chi^2(2) = 1.20$, $p = 0.55$) (Fig. 2). Despite the lack of any significant effect of Condition of motor DTCs, significant motor DTCs for ML stepping accuracy (significantly greater stepping errors during Dual- compared to Single-task) were observed during both Threat ($Z = -1.93$, $p = 0.027$, $r = 0.50$) and Internal ($Z = -2.16$, $p = 0.016$, $r = 0.56$) (Fig. 2). Significant motor DTCs for gait speed (significantly slower gait during Dual-task) were also were also observed for: Baseline ($t(14) = -3.20$, $p = 0.003$, $d = 1.17$), Threat ($Z = -2.57$, $p = 0.006$, $r = 0.66$) and Internal ($t(14) = -3.78$, $p = 0.001$, $d = 1.38$) (Fig. 2).

3.3. Correlational analyses

During Threat, state-CMP was significantly positively correlated with cognitive DTCs ($r = 0.47$, $p = 0.04$) (Fig. 3), while fear of falling was significantly negatively correlated with motor DTCs for ML stepping accuracy ($r = -0.66$, $p = 0.008$). Gait speed DTCs were not significantly correlated with any other DTC variables (p's > 0.11).

4. Discussion

As predicted, significantly greater cognitive DTCs were observed during Threat, compared to Baseline (Fig. 2). Moreover, state-CMP was significantly correlated with cognitive DTCs during Threat, indicating that the greatest cognitive DTCs were observed in the individuals directing the most attention towards conscious motor control.

We also observed significantly greater cognitive DTCs for Internal (during which participants reported significantly greater conscious movement control), compared to Baseline. This finding demonstrates evidence of a causal link between conscious movement control and impaired attentional processing efficiency during gait. This finding confirms the assumption that consciously attending to movement processes is attention demanding and reduces resources available for carrying out secondary tasks during gait. These results extend existing literature which has implicated conscious movement processing as placing increased demands on cognitive resources during locomotion [10,11], as well as in other tasks, such as sporting movements [23], complex decisions [24] and mental arithmetic [25].

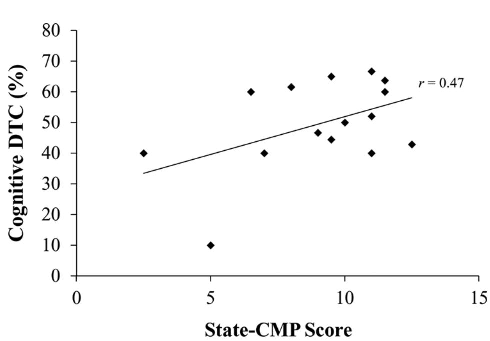

Fig. 3. Correlation between cognitive DTCs (%) and State-CMP scores during Threat.

Attentional processing inefficiencies have been previously reported in individuals when walking at height [4]. Gage et al. [4] speculated that fall-related anxiety may impact attentional processing as a consequence of increased cognitive resources being directed towards the control of gait. Results from the present study provide empirical evidence for this relationship; implicating conscious movement control as the mediating variable in the relationship between fall-related anxiety and attentional processing inefficiencies. One population for whom fall-related anxiety is a prevalent problem is older adults [6,26]. Attentional processing inefficiencies have been reported in older adults anxious about falling [4,5], with these inefficiencies associated with poorer stepping performance [5]. Future research should, therefore, assess the degree to which these inefficiencies observed in anxious older adults are a consequence of increased conscious movement processing.

Despite the comparable increases in both conscious movement control and cognitive DTCs during Threat and Internal (and the significant correlation observed between state-CMP and cognitive DTCs during Threat), we cannot be certain that these processing inefficiencies are underpinned by the same mechanism (i.e., conscious movement control). For example, research demonstrates attentional processing inefficiencies in anxious individuals irrespective of any change in conscious movement processing [2,3]; through the likely mechanism of ruminative thoughts/worries [3]. Therefore, one cannot dismiss the potential influence of other anxiety-related mechanisms during Threat.

The increased cognitive DTCs observed during both Threat and Internal were accompanied by significant motor DTCs for ML stepping accuracy, highlighting poorer stepping accuracy during Dual, compared to Single-task, trials in both Threat and Internal (Fig. 2). No such Dual-task related declines in stepping accuracy were observed during Baseline. This result was unexpected, as we predicted that directing attention towards movement during Threat and Internal would have resulted in participants adopting a 'posture-first' strategy; whereby the motor task would have been prioritised above the cognitive task during Dual-task trials, resulting in maintained motor dual-task performance. While participants did direct attention towards consciously controlling movement during both Threat and Internal, significant motor DTCs were also observed during these conditions.

Stepping is a visually guided action, requiring both online and feedforward visual control [27,28]. Research demonstrates that effective visual search during adaptive gait requires cognitive resources [11]. Consequently, we propose that attempting to consciously control one's movement whilst simultaneously performing a secondary cognitive task limited the attentional resources available for carrying out other processes necessary for performing the motor task; such as feedforward visual planning [6]. Indeed, Uiga and colleagues [12] propose that adopting an internal focus during gait may increase fall-risk by reducing the likelihood of perceiving external information necessary for successful locomotion. Future research should look to further examine these speculations.

One limitation of the present research relates to the aggregating of the state psychological measures across each experimental block (which contained both Single- and Dual-task walks), rather than measuring these on a trial-by-trial basis. It is possible that the arithmetic dual-task may have acted as a 'distracter', with individuals less able to focus on consciously processing their movement during Dual-task; and that the higher state-CMP scores observed during Threat and Internal represent greater conscious motor processing during Single-task only. However, measuring the impact of a secondary task during motor performance is a common method to assess movement automaticity [23,24], under the assumption that conscious movement control places greater demands on cognitive resources. As Kal et al. [29] note, "the execution of a secondary task is expected to interfere with performance on a consciously controlled motor task […] but should not − or to a lesser extent − affect performance on an automatized task" (p. 528). Therefore, if participants only consciously controlled their movement during Single-task, we would not expect to observe increased DTCs during Threat or Internal (as this line of argument would propose that conscious control would have 'returned' to Baseline levels during Dual-task trials in these two conditions). Furthermore, as these measures were used to assess the relationship between state psychological functioning and DTCs (which, themselves, are a composite score of Single- and Dual-task performance), we determined it necessary to aggregate these measures across trials of both Single- and Dual-task.

5. Conclusions

These results demonstrate evidence of a causal link between conscious movement control and impaired attentional processing efficiency during gait. They also implicate conscious movement control as a potential mediator between fall-related anxiety and impaired attention processing, supporting speculations made previously by Gage et al. [4]. Further work is needed to examine these links within the context of elderly falls.

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