Dual-task prioritization during overground and treadmill walking in healthy adults

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1. Introduction

The cognitive control of walking is typically examined using a dual-task paradigm, in which a cognitive task is simultaneously performed during walking. Alterations to either walking or cognitive task performance, a dual-task effect, are suggested to arise from competition for resource limited control processes and indicate that both tasks are controlled by the same cognitive processes [1,2]. The magnitude of these dual-task effects is linked to fall risk in several clinical populations [1]. Treadmill dual-task walking paradigms are frequently used to assess age and disease related differences in the cognitive control of gait [3,4] and its neural correlates [5–8]. Although it is assumed that these findings transfer to overground walking, recent research has demonstrated differences in dual-task performance between the two walking modalities, and these discrepancies have been suggested to indicate differing control strategies [9,10]. Inferences about brain-and behaviour relationships drawn from treadmill dual-task walking may thus not reflect those during typical overground walking.

During overground walking, walking speed is reduced and the stride-to-stride variability of stride time, frequently interpreted as a measure of walking stability, is increased [10,11]. Dual-task theorists have used these findings as evidence that overground walking requires cognitive control, because performance of a simultaneous cognitive task interferes with the control of gait [1]. In contrast, during treadmill dual-task walking, stride time variability is often reported to be reduced [4,12] or unchanged [9,10], which has been interpreted as evidence that treadmill walking requires less cognitive control, allowing participants to perform the cognitive task without detrimental changes to gait [4,12]. The model of dual-task prioritization suggests that whether one prioritizes walking or cognitive performance during dual-task walking is dependent on the physiological and cognitive capacity of the walker, and the postural, sensorimotor, and cognitive demands of the tasks [13]. There is increasing evidence that young adults prioritize cognitive task performance during dual-task walking [11,14,15]. Differences in the effects of this prioritization may explain the differences between the dual-task effects on overground and treadmill walking: prioritization of the cognitive task during overground walking may come at the expense of walking performance [11]. On the treadmill however, prioritization of the cognitive task does not appear to influence walking. It is possible that the additional mechanical force from a motorised treadmill either reduces the capacity demands on control processes to exert forces or artificially constrains gait speed and reduces degrees of freedom to be controlled during dual-task walking [10]. Dual-task prioritization strategies can be examined by manipulating task prioritization instructions [14,16]. Healthy adults are able to increase overground walking speed and improve cognitive task performance when asked to prioritize either walking or cognitive task respectively [11,16]. If the dual-task effects on walking performance are because participants prioritize the cognitive task, then the dual-task effects of explicit prioritization of the walking task would be expected to be different to typical dual-task performance, or those during explicit prioritization of the cognitive task.

The present study had two aims: 1) to replicate previous reports of dual-task effects on overground, but not treadmill walking and 2) to examine whether differences in the dual-task effect on overground and treadmill walking were due to differences in task prioritization. We hypothesized that there would be a dual-task effect on overground, but not treadmill walking, replicating previous reports [9,10,]. We also hypothesized that, when compared to typical no prioritization dual-task walking, there would be no difference between the dual-task effects when young adults prioritized cognitive task performance, indicating that walkers prioritize the cognitive task in both conditions, but that this prioritization has very different walking dual-task effects.

2. Method

2.1 Participants

Previous studies (e.g. [15]) report large effects of prioritization instructions on walking performance (partial eta squared = 0.69). To control for the possibility that these effects may be smaller in the population, we used a lower bound estimate of a "large" effect size (partial eta squared = 0.26) as the estimated effect size of interest. 21 participants would be required to detect this effect (α= 0.05, β = 0.9) in a one-way repeated measure ANOVA (see "Data analysis" below). Exclusion criteria for the study included known gait dysfunction, contraindications to walking exercise, neurological conditions or dyscalculia. Inclusion criteria included aged 18-60 years old, able to walk on a treadmill, able to understand instructions given in English and English able to count for 120 s using English words for numbers. All participants gave written informed consent prior to participating following institutional ethical approval.

2.2 Procedure

Following familiarisation to the experimental procedures, participants were asked to perform a cognitive task (see 'cognitive task performance' below) whilst seated (single task). Participants then walked on both a motorised treadmill (Life fitness CLST, Life Fitness, Cambridge, UK) and overground along a 12 m walkway with 1 m turning zones at each end. For both walking modalities, participants performed four different conditions, each lasting for 120 s. Initially, participants were instructed to walk as comfortably and as naturally as they could in silence (single-task condition). Participants were then asked to walk whilst performing the cognitive task (dual task) and to either prioritize their walking performance (DTwalk), their cognitive task performance (DTcog) or prioritize neither task (DTno). By comparing the effects of prioritizing either the walking or cognitive tasks to those when neither task is prioritized, it is possible to determine the effect of walking environment on task prioritization [14,16]. The verbal instructions for these tasks were as follows: “walk as comfortably and as naturally as you can”, during DTwalk, and “perform as many subtractions as accurately as you can” during DTcog. Typically, DTwalk prioritization instructions asks walkers to prioritize speed [11], but these instructions are not relevant for treadmill walking, where the speed is mechanically controlled. Dual-task condition order was balanced and walking condition order was counterbalanced across participants using a Latin square design. Preferred treadmill walking speed was determined using an established technique [12]. Briefly, participants started walking at 2.0 $km.h^{-1}$, whilst speed was increased in 0.1 km.h-1 increments until the participant reported that the speed equalled their preferred walking speed. The treadmill speed was then increased to 6.5 $km.h^{-1}$ and lowered in 0.1 km.h-1 increments until the participant again identified their preferred speed. This process was repeated four times and the mean of the identified preferred walking speeds was used as the preferred walking speed. Participants walked at their preferred treadmill walking speed for 15-20s before recording began.

2.3 Measures

Gait analysis

Gait variables were recorded using a wireless gait analysis system which consisted of three body worn sensors, each containing a gyroscope (OPAL, APDM, Portland, USA, for details see [17–19]. The sensors transmitted their data online to a wireless receiver linked to the Mobility Lab software package (Version 1, APDM, Portland, USA). Three separate temporal events, heel strike, toe off and mid-swing were identified through changes in shank angular velocity [20]. Spatiotemporal gait parameters were derived from a validated two-link inverted pendulum model [20]. Mean (left plus right leg) stride velocity ($m.s^{-1}$), stride time (s) and stride time variability (the coefficient of variation of stride time, %) were recorded. Relative reliability was chosen as a measure of stride variability because it allows comparison between groups and walking conditions where mean values may differ, but variation may (or may not be) similar. For overground walking, stride variables recorded immediately before and during turns were removed from the analysis [18,21].

Cognitive task performance

Participants performed serial subtractions in sevens from a number between 590-599 which was recorded using a portable digital dictaphone (UX200, Sony, Tokyo, Japan) and analysed off-line. The starting number for each trial was selected using the pseudo-randomisation function in Microsoft Excel (Version 2013, Microsoft Corporation, Redmond, USA). The number of correct responses and errors were recorded. Participants were instructed to make as many correct subtractions as possible in 120 s. Cognitive task performance (CT) was calculated using the following equation [10]:

$$Number\ of\ correct\ answers\ -\ Number\ of\ errors$$

Equation 1. Calculation of cognitive task performance

2.4 Data Analysis

The dual-task effect for each variable was calculated. The dual-task effect is a measure of relative change (%) from single to dual-task conditions and was calculated using the following equation [23]:

$$\left(\frac{Dual\ task\ value - Single\ task\ value}{Single\ task\ value}\right) \times\ 100$$

Equation 2. The dual-task effect

For stride velocity, cognitive task performance, a negative dual-task effect represented a decline in performance (a reduction in walking speed and worse cognitive performance, respectively), a positive effect - an improvement in performance. For stride time and stride time variability, a positive dual-task effect represented worse performance. All statistical analyses were performed in R, using the jamovi software package (Version 0.9,[22]). Data were checked for normality using the Shapiro-Wilk's test, non-parametric statistical tests were used if data violated normality assumptions. To address aim 1, the dual-task effect on overground and treadmill walking and cognitive performance during DTno were compared to no effects (i.e. 0) using one sample T-tests and Wilcoxon signed rank tests. The difference between the dual-task effect on walking and cognitive performance between the two walking modalities during DTno were examined using paired sample T-tests or Wilcoxon signed rank tests. The Holm-Bonferroni correction was used to adjust for multiple comparisons.

The effects of prioritization on the dual-task effect on walking and cognitive task performance (aim 2) were compared for each walking modality using one-way repeated measure ANOVA or Friedman's ANOVA with priority condition (DTno x DTwalk x DTcog) as the within subject variable. The Greenhouse-Geisser correction was used when data violated the assumption of sphericity. Interaction effects were followed up using Holm-Bonferroni corrected Student's T-tests or Wilcoxon signed-rank tests. For all pairwise comparisons, Cohen's d (*d,* for Student's T-tests) and *r* (for Wilcoxon signed-rank tests) were used as standardized estimates of the effect size. *r* was calculated using the following equation:

$$\frac{Z\ Score}{\sqrt{Number\ of\ observations}}$$

Equation 3. The calculation of *r*

The threshold for rejecting the null hypothesis was set at $p < 0.05$.

3. Results

Twenty-two healthy young adults (15 females, mean ± SD: age, 22 ± 2 years; body mass, 67.1 ± 11.1 kg; height, 168 ± 10 cm) were recruited for this study. The mean±SD for stride velocity, stride time, stride time variability and cognitive task performance is displayed in Table 1.

Table 1 here please

3.1 Dual -task effects on walking performance

To address aim 1, we examined whether the dual-task effect on walking was significantly different to 0 during overground and treadmill walking. Overground dual-task walking was slower and more variable than single task walking. There was a negative dual-task effect on stride velocity ($T_{(21)}$ = 5.6, p = 0.003, d = 1.2, Figure 1, top right panel), and positive dual-task effects on stride time ($T_{(21)}$ = 3.7, p = 0.003, d = 0.8, Figure 1 top left panel) and stride time variability (W = 217.0, p = 0.004, r = 0.6, Figure 1, bottom left panel). During treadmill walking, there was no dual-task effect on stride velocity ($T_{(21)}$ = 0.7 p = 0.481, d = 0.2), stride time ($T_{(21)}$ = 1.8, p =0.081, d = 0.4) or stride time variability ($T_{(21)}$ = 1.8, p = 0.093, d = 0.4).

The dual-task effect on stride velocity ($T_{(21)}$ = 5.4, p = 0.003, d = 1.2), stride time ($T_{(21)}$ = 2.9, p = 0.016, d = 1.2) and stride time variability (W = 1.0, p = 0.003, r = 0.5) were higher during overground walking compared to treadmill walking.

Figure 1. Here please

3.2 Dual-task effect on cognitive performance

There was no dual-task effect on cognitive performance during overground walking (W = 108.0, p = 0.926, r = 0.3) but there was a positive dual-task effect on cognitive task performance during treadmill walking ($T_{(21)}$ = 2.7, p = 0.042, d = 0.6, Figure 1, bottom left panel) where cognitive task performance was improved, compared to single task walking, during dual-task walking. There was no difference in this effect between overground and treadmill walking (W = 63.0, p = 0.242, r = 0.2).

3.3 Effect of prioritization on walking performance

To address, aim 2, we examined whether explicit prioritization instructions influenced the control of dual-task gait, and compared these effects to dual-task walking with no explicit prioritization. During overground walking, there was a main effect of prioritization instructions on the dual-task effect on stride velocity ($F_{(2,42)} = 4.2$, $p = 0.022$). The dual-task effect on stride velocity was lower during DTcog compared to DTwalk ($T_{(42)} = 2.8$, $p = 0.042$, $d = 0.6$), representing a greater dual-task decrease in overground stride velocity when participants were instructed to prioritize the cognitive task prioritization, compared to the decrease during when asked to prioritize the walking task. However, inspection of the raw data (Table 1) indicates that the absolute effect size for this difference, 0.02 m.s, is unlikely to be meaningful [20]. There was no difference in the dual-task effect on stride velocity between the DTcog and DTno conditions ($T_{(21)} = 2.0$, $p = 0.122$, $d = 0.4$), or between the DTno and DTwalk conditions ($T_{(21)} = 0.7$, $p = 0.466$, $d = 0.2$). There was no effect of prioritization instructions on the dual-task effect on stride time ($X^2_{(2)} = 5.1$, $p = 0.078$) or stride time variability ($X^2_{(2)} =1.2$, $p = 0.554$).

During treadmill walking, there was no effect of prioritization instructions on the dual-task effect on stride velocity ($F_{(2,42)} = 2.3$, $p = 0.116$), stride time ($F_{(1,30)} = 3.3$, $p = 0.066$), or stride time variability ($F_{(2,42)} = 0.5$, $p = 0.637$).

3.4 Effect of prioritization on cognitive task performance

During overground walking, there was an effect of prioritization instructions on the dual-task effect on cognitive task performance ($X^2_{(2)} = 9.4$, $p = 0.009$, Figure 3A). The dual-task effect was higher during DTcog compared to DTwalk ($W = 32.5$, $p = 0.006$, $r = 0.4$) representing an improvement, compared to single task performance in cognitive task performance during dual-task walking when participants were asked to prioritize the cognitive task, compared to when they were asked to prioritize the walking task . There was no difference between DTwalk and DTno (*W* = 65.5, *p* = 0.170, *r* = 0.2) or between DTcog and DTno (*W* = 147.5, *p* = 0.274, *r* = 0.1).

During treadmill walking there was also a significant effect of prioritization instructions on the dual-task effect on cognitive task performance ($X^2_{(2)}$ = 9.4, *p* = 0.009, Figure 2B). The dual-task effect was higher during DTcog compared to DTwalk (*W* = 30.0, *p* = 0.003, *r* = 0.5). The dual-task effect was also higher during DTno compared to DTwalk (*W* = 329.0, *p* = 0.010, *r* = 0.4) representing an improvement in cognitive task performance during dual-task walking when participants were asked to prioritize the cognitive task or neither task, compared to when they were asked to prioritize the walking task. There was no difference between DTcog and DTno (*W* = 133.0, *p* = 0.555, *r* < 0.1).

Figure 2. Here please

4. Discussion

The present study examined the difference between the dual-task effects on overground and treadmill walking, and the effect of explicit task prioritization on the dual-task effects in both walking modalities. As hypothesized, there was a dual-task effect on overground but not treadmill walking. Prioritizing walking performance reduced cognitive task performance in both overground and treadmill dual-task walking, but did not alter the dual-task effect on walking. The dual-task effect on walking performance was different between overground and treadmill walking. Healthy adults appear to prioritize cognitive task performance during treadmill dual-task walking, . Caution is advised when extrapolating walking dual-task effects on treadmill walking performance to overground walking in healthy adults.

In the present study, the dual-tasks effects on walking were different between walking modalities. The dual-task effects on walking were much greater during overground walking compared to treadmill walking. Indeed, whilst overground dual-task walking significantly reduced walking speed and increased stride to stride variability, there was no dual-task effect on treadmill walking. In contrast, cognitive task performance increased during treadmill dual-task walking. There is a considerable body of evidence showing that kinematic gait parameters differ between treadmill and overground walking [21,23,24]. These results replicate and extend previous reports in young [10] and old [9] healthy adults that the dual-task effect differs between the two walking modalities. Researchers interested in dual-task walking are, presumably, concerned with the factors which are associated with, and influence, dual-task walking in the community. i.e. during overground walking. Although treadmill walking is often used to describe differences in dual-task performance, and the inferred relationships to fall risk and cognitive function, between populations [3,4], these results add to the evidence that the dual-task effects on walking performance during treadmill walking are not the same as those during overground. Based on the results of this and previous [9,10] studies, the use of treadmill dual-task walking paradigms in healthy adults is not advised. However, it is not clear whether these results will also apply to populations in whom dual-task effects on walking are more profound, such as in older adults or clinical populations [25]. It is also not clear whether these effects generalize to other dual-tasks, such visual attention tasks, which have previously been shown to exert dual-task effects on treadmill walking in healthy adults [26]. Examination of the role of task, and the difference between modalities in other populations, may provide insight into the factors which contribute the dual-task effect on walking.

Cognitive task performance was improved during treadmill dual-task walking when participants were instructed to prioritize neither task, or prioritize the cognitive task. This effect occurred without a concomitant change to walking performance. However, this effect was absent when participants were instructed to focus on the walking task. This finding suggests that participants typically prioritize cognitive task performance during treadmill dual-task walking, in accordance with previous reports [11,14–16]. The effect of prioritization instructions on overground walking was more complex. Instructing participants to prioritize cognitive task performance led to a statistically significant positive dual-task effect on stride velocity, representing a dual-task reduction in walking speed. This effect occurred with a concomitant improvement in cognitive task performance, which is not seen when participants are asked to prioritize neither task. This result may indicate that participants typically do not prioritize the cognitive task during overground walking. However, the reduction in walking speed (a positive dual-task effect on stride velocity) may be within the error of this measure, and thus it is difficult to say from the present data which task, if any, was prioritized during overground walking performance. Although the exact reasons for this disparity are unclear, it is possible that during treadmill dual-task walking, the consistent mechanical force from the treadmill can be used to stabilizes the walking pattern and free up sufficient resources for the cognitive task even when attention was directed away from walking. As a result, cognitive resources do not reach capacity and are not constrained. Alternatively, the mechanical influence of the treadmill on the walking pattern may prevent measurable changes in the spatiotemporal gait parameters recorded here. In contrast, during overground walking, where assistance with the control of walking is absent, allocating even some attention to the cognitive task impairs walking performance. In contrast to both our hypotheses, and previous reports [11], asking healthy adults to prioritize the walking task did not influence the dual-task effect on overground walking speed. It is possible that the instructions given here, "walk as comfortably and as naturally as you can" meant that participants were not focussed on improving walking speed as much as maintaining a stable walking pattern. It is likely that with instructions to walk as fast as possible the negative dual-task effects on walking speed may have been reduced [11].

5. Conclusion

The present study examined whether dual-task effects, and prioritization strategies differed between overground and treadmill walking. There was a walking dual-task effect on overground but not treadmill walking, replicating previous reports. Participants appeared to prioritize cognitive task performance during both overground and treadmill dual-task walking, and this prioritization led to very different effects on walking performance. These results suggest that previous reports of age-related differences in performance and neural activation during treadmill walking may be influenced by young adults' tendency to prioritize the cognitive task, which does not happen during overground walking. Future studies are thus advised to use an overground walking paradigm for dual-task studies to improve the ecological validity of the paradigm.

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