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Effects of instructed focus and task difficulty on concurrent walking and cognitive task performance in healthy young adults

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Abstract

Dual task paradigms can be used to examine the interactions between cognition and the control of posture and gait. Measuring and interpreting changes in dual task performance is challenging, however, because many factors can influence performance. This study examined the effects of instructed focus and walking task difficulty, and the interaction between these factors, on dual task performance in healthy young adults. Fifteen participants performed a cognitive task while walking with either a usual base or a narrow base of support. Participants were instructed to focus on either the cognitive task or walking. Trade-offs both within and between tasks were assessed using the modified attention allocation index and the performance operating characteristic. Instructed focus influenced both the cognitive task and walking. Performance on the cognitive task was faster with instructions to focus on the cognitive task, and walking was faster (and more accurate in the narrow-base condition) with instructions to focus on walking. Walking task difficulty did not affect cognitive performance but did affect walking, with faster walking in the usual-base versus narrow-base condition. There was evidence of an interaction, with greater effects of instructed focus on the cognitive task during usual versus narrow-base walking. These results support the idea that the ability to flexibly shift attention allocation and task performance in response to instructions depends on the difficulty of the postural control task. The modified attention allocation index and the performance operating characteristic were instrumental in fully characterizing trade-offs between and within tasks in order to understand dual task performance changes. A clearer understanding of the factors that affect dual task walking and the interactions between these factors has important implications for the assessment of dual task performance in both clinical and research settings.

Keywords

Attention; Instructional set; Dual task; Gait; Narrow-base walking

Introduction

Functional mobility often requires that a person walk while performing concurrent tasks, such as talking or carrying an object. The ability to maintain balance under such dual task conditions relies on the successful interaction between neural mechanisms that regulate postural control and those that regulate the coincident cognitive or motor task. Interference between two tasks suggests that shared resources or processes may be involved in the

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regulation of both postural control and the concurrent task. Thus, research utilizing dual task paradigms can provide important insights into the interactions between cognition and the control of walking. However, measuring and interpreting changes in dual task performance is complex. Many factors, such as instructions, task difficulty, and individual capabilities, can affect performance (Woollacott and Shumway-Cook 2002; Huxhold et al. 2006; Fraizer and Mitra 2008; Yogev-Seligmann et al. 2008). In addition, evaluating trade-offs between tasks (e.g., faster gait speed but slower cognitive task response speed) and within each task (e.g., slower cognitive task response speed but greater response accuracy) is critical for characterizing changes in dual task performance.

Previous research indicates that postural task difficulty influences concurrent cognitive task performance (Lajoie et al. 1993, 1996), though this effect may be greater in older versus young adults. Increased stance postural control demands due to perturbations (Brown et al. 1999; Rapp et al. 2006) or altered sensory contexts (Shumway-Cook and Woollacott 2000) cause a decline in cognitive performance in older, but not younger, adults. Increased walking task difficulty (e.g., obstacle crossing) affects cognitive task performance in both young and older adults (Brown et al. 2005). These results suggest that more complex postural control tasks may require greater cognitive resources.

Instructed focus also influences dual task performance of stance and gait. In young adults, performance of a visuospatial memory task while standing improves with instructions to focus on the cognitive task, but stance postural control is not influenced by instructions (Siu and Woollacott 2007). Dual task walking performance is also affected by instructions in both young and older adults, though the effect of instructions seems to be greater in young adults (Siu et al. 2008; Yogev-Seligmann et al. 2010). For example, during dual task obstacle crossing, both younger and older adults decrease response latency on an auditory choice reaction time task with instructions to focus on the cognitive task and increase gait speed during obstacle crossing with instructions to focus on walking (Siu et al. 2008). Although the use of different cognitive tasks in these studies limits any direct comparison of results, these results suggest that the difficulty of the postural control task may influence the response to instructed focus during dual task conditions. Dual task interference may be limited with relatively simple postural tasks, such as quiet stance, resulting in optimal dual task performance of these tasks regardless of instructions. As noted above, other postural tasks, like walking, demonstrate dual task performance changes that are responsive to instructions. As the postural task becomes more difficult, however, it may impose the need for a posture-first strategy in order to preserve stability. This posture-first strategy may in turn minimize the ability to flexibly shift attention allocation and task performance in response to instructed focus.

This study examined the effects of instructed focus and walking task difficulty, and the interaction between these factors, on dual task walking and cognitive task performance in healthy young adults. We anticipated that instructed focus would affect both walking and cognitive task performance, such that performance of each task would be optimized with instructions to focus on that task. Further, we expected that these effects would be modified by walking task difficulty. A reduced effect of instructions under more complex walking conditions would be consistent with the idea that challenging postural tasks may impose a posture-first prioritization. Alternatively, healthy young adults may have sufficient postural control capabilities to flexibly allocate attention and modify task performance in response to instructions even under challenging walking conditions.

Methods

Participants

Participants were 15 healthy young adults (mean [SD] age: 26.4 [4.3] years; height: 1.69 [0.11] m; mass = 66.1 [10.5] kg; 6 male/9 female). Participants completed a medical history and cognitive status screening. Exclusion criteria included orthopedic or neurological conditions that affected walking and significant visual, auditory, or cognitive impairments that affected the ability to complete this protocol. Written informed consent was obtained in accordance with approved institutional review board procedures.

Experimental procedures

Cognitive task—Participants performed an auditory analogue of the Stroop test (Morgan and Brandt 1989; Siu et al. 2008), which consists of the words “high” and “low” said in either a high or low pitch (average stimulus length = 470 ms). Instructions were to “respond as quickly and as accurately as possible” by stating the pitch. Four different stimuli were presented. Congruent stimuli were those in which the word and the pitch were the same (i.e., the word “high” said in a high pitch and the word “low” said in a low pitch). Incongruent stimuli were those in which the word was said in the opposite pitch (i.e., the word “high” said in a low pitch and the word “low” said in a high pitch). Cognitive stimuli were pseudo-randomized in order to present equal numbers of each of the four stimuli and were presented in blocks of 20 trials. Each trial was 3 s long and began with a variable 0- to 1-s delay between the start of the trial and the presentation of the stimulus. A wireless headset and microphone system (Plantronics, Inc., Santa Cruz, USA; Jabra Corporation, Nashua, USA) was integrated with custom hardware and software for data collection and analysis. Participants performed three training blocks while sitting in order to provide practice and minimize learning-related influences during the rest of the experiment. Results from the training block were not included in the analysis. Three blocks of seated single task performance (60 trials) were interspersed throughout the experiment, at the beginning, middle, and end of the testing session. Two blocks of the cognitive task (40 trials) were performed during each dual task walking condition, where participants walked continuously throughout the block. The cognitive task outcome measures were response latency and response accuracy, which were assessed throughout each block. Response latency was defined as the time from stimulus onset to response onset. Response accuracy was defined as the number of correct responses divided by the total number of responses, expressed as a percentage.

Walking tasks—Participants walked on level ground along a 6-m pathway under two conditions: usual-base (UB) walking was the simple walking condition and narrow-base (NB) walking was the more difficult walking condition. Participants were asked to walk with arms crossed for all conditions. The NB path width was normalized to 50% pelvic width for each participant (average width = 14 cm) (Kelly et al. 2008) and was displayed with tape on the floor. For UB walking, instructions were to “walk as quickly as possible.” For NB walking, instructions were to “walk as quickly and as accurately as possible” within the path. Single task walking was performed in separate blocks at the beginning and end of each walking condition. Participants walked continuously during all single and dual task walking blocks, including turns at the end of the walkway. A Qualisys Motion Capture system (Qualisys, Gothenburg, Sweden) recorded the position of markers placed on the NB path and bilaterally on the heel, forefoot (between the 2nd and 3rd metatarsal–phalangeal joint), lateral malleolus, tibial tuberosity, lateral knee joint, patella (superior border), greater trochanter, anterior superior iliac spine, iliac crest, acromion, sternum, and thorax. Walking was recorded in the middle 3–4 m of the walkway only, when participants were walking in a straight line. For both UB and NB walking, gait speed was measured as the distance traveled by the ankle joint center during each stride (i.e., one heel strike to the next heel strike of the same foot) divided by the stride time (i.e., time between one heel strike and the next heel strike of the same foot). For NB walking, step accuracy was also measured as the lateral ankle joint position at heel strike relative to the NB path. An accurate step was one in which the ankle marker fell on or within the path boundary. Step accuracy was the number of accurate steps divided by the total number of steps, expressed as a percentage. For inaccurate steps, the step error magnitude was calculated as the distance between the ankle marker and the path boundary.

In addition to these primary outcome measures, several spatiotemporal measures were used as secondary variables to further characterize changes in walking. Stride length was defined as the distance (length) between the ankle joint center at one heel strike and the ankle joint center at the next heel strike of the same foot. Step width was calculated as the distance (width) between the ankle joint center of one foot at heel strike and the ankle joint center of the opposite foot at heel strike. Cadence, or the rate of stepping, was defined as the number of steps per minute. Step width variability and stride time variability were expressed as the coefficient of variation (i.e., the standard deviation divided by the mean and multiplied by 100%).

Dual task conditions—Single task walking was performed at the beginning and end of the testing session. Single task cognitive blocks were performed at the beginning, middle, and end of the session. Dual task conditions were pseudo-randomized with respect to task difficulty and instructed focus. The order of UB versus NB walking was randomized. Within each walking condition, the order of instructed prioritization was randomized between one of two instructional sets. In the cognitive focus condition, instructions were “focus 100% on the cognitive task, and perform it as quickly and as accurately as you did when you were sitting.” For the walking focus condition, instructions were “focus 100% on walking, and walk as quickly (and as accurately, in the NB condition) as you did when you were only walking.” The specific wording of these instructions was based on results from preliminary testing of the experimental protocol.

Assessing dual task performance

Absolute and relative changes—The effects of instructed focus and walking task difficulty were assessed using absolute values of gait speed, step accuracy (in the NB condition), response latency, and response accuracy. In addition, a relative measure of change, the dual task effect (DTE), was calculated for each outcome measure. A decrement under dual task conditions (i.e., a dual task cost) was represented by a negative value. An improvement under dual task conditions (i.e., a dual task benefit) was represented by a positive value. Because decreases in gait speed, step accuracy, and response accuracy represent performance decrements, these DTEs were calculated as follows:

$$\frac{(\text{dual task} - \text{single task})}{\text{single task}} \times 100\%$$

An increase in response latency (i.e., slower response latency) represents a performance decrement; therefore, response latency DTE was calculated as follows:

$$\frac{-(\text{dual task} - \text{single task})}{\text{single task}} \times 100\%$$

Trade-offs within tasks—The attention allocation index measures the ability to allocate attention in response to instructed focus (Siu and Woollacott 2007; Siu et al. 2008). We calculated a modified attention allocation index (mAAI) using DTE values to assess trade-offs within each task. Positive values indicate a shift in task performance toward the instructed task, and negative values indicate a shift away from the instructed task. The mAAI for walking variables was calculated as follows:

$$\text{walking focus DTE} - \text{cognitive focus DTE},$$

where walking focus DTE represents DTE values in the walking focus condition and cognitive focus DTE represents values in the cognitive focus condition. The mAAI for cognitive variables was calculated as follows:

$$\text{cognitive focus DTE} - \text{walking focus DTE}.$$

Trade-offs between tasks—Trade-offs between tasks were examined using a performance operating characteristic (POC), in which cognitive task and walking DTEs were plotted against one another. The performance (or attention) operating characteristic was originally devised to examine whether two tasks interfere with one another and how the performance of one task varies with the performance of another (Norman and Bobrow 1975; Sperling and Melchner 1978). We used the POC to determine the degree of dual task interference and how performance shifts in response to instructed focus and task difficulty. Composite DTE values were calculated for each task in order to assess overall task performance despite possible trade-offs within each task. Composite DTE values were then used to plot the POC. The UB walking DTE was defined by gait speed alone, because there were no accuracy requirements for this task. Gait speed and step accuracy DTEs were summed for the NB walking DTE. The NB walking DTE was used to examine overall changes in walking performance, regardless of trade-offs between gait speed and step accuracy. Response latency and response accuracy DTEs were summed for the cognitive task DTE. Similarly, the cognitive task DTE was used to examine overall changes in cognitive task performance, regardless of trade-offs between response latency and response accuracy.

Statistical analysis

The effects of instructed focus and task difficulty on absolute values and DTEs for gait speed, all spatiotemporal gait measures, response latency, and response accuracy were analyzed using repeated measures analysis of variance with 2 factors: instructed focus (walking vs. cognitive) and walking task difficulty (UB vs. NB; SPSS Statistics 17.0, Chicago, USA). Step accuracy and step error magnitude were only measured during NB walking, so the effect of instructed focus was assessed using a repeated measures analysis of variance with only one factor. For the cognitive task, performance of congruent and incongruent trials was compared in a secondary data analysis. For single task conditions, the effect of congruency on response latency and response accuracy was examined using *t*-tests. For dual task conditions, the effect of congruency was examined using a repeated measures analysis of variance with 3 factors: instructed focus, walking task difficulty, and congruency (congruent vs. incongruent). The level of significance for all statistical tests was set at α = 0.05.

Results

Cognitive task

Table 1 shows absolute and relative values for all variables. Under single task conditions, mean (SD) response latency was 0.65 (0.10) s and response accuracy was 99.2 (1.1)%. Congruent stimuli had shorter response latencies (congruent: 0.61 s; incongruent: 0.70 s; $P < 0.001$) and higher response accuracy (congruent: 100%; incongruent: 98%; $P = 0.01$) than incongruent stimuli.

Figure 1 shows the effects of instructed focus and walking task difficulty on absolute measures of cognitive task performance. Instructed focus affected response latency (Fig. 1a), with longer latencies in the walking focus condition (walking: 0.83 s; cognitive: 0.69 s; main effect: $P < 0.001$). In contrast, the difficulty of the walking task did not affect response latency (main effect: $P = 0.20$). There was a trend toward an interaction between instructed focus and task difficulty, with a larger effect of instructed focus in the UB versus NB condition ($P = 0.09$). The same pattern of effects was shown for response latency DTEs, a relative measure of performance. There was a significant main effect of instructed focus on response latency DTEs (walking: −27.5%; cognitive: −5.5%; main effect: $P < 0.001$), no effect of task difficulty (main effect: $P = 0.22$), and a trend toward an interaction ($P = 0.07$). Under dual task conditions, congruent stimuli again had shorter response latencies than incongruent stimuli (congruent: 0.80 s; incongruent: 0.71 s; $P < 0.001$). No interaction effects between congruency and instructed focus ($P = 0.82$) or walking task difficulty ($P = 0.27$) were found.

Response accuracy (Fig. 1b) was >98.5% in all conditions, with no main effects of instructions ($P = 0.36$) or task difficulty ($P = 0.32$) and no interaction effect ($P = 0.27$). Similarly, all response accuracy DTEs were between −1 and 1%, with no main effects of instructed focus ($P = 0.33$) or task difficulty ($P = 0.36$) and no interaction effect ($P = 0.27$). Under dual task conditions, congruent stimuli had higher response accuracy than incongruent stimuli (congruent: 100%; incongruent: 99%; $P = 0.02$). There were no interaction effects between congruency and instructed focus ($P = 0.32$) or walking task difficulty ($P = 0.79$).

Walking

For single task walking conditions, an average of 17 strides per participant were analyzed for each condition. For dual task walking conditions, an average of 15 strides per participant were analyzed for each condition. Single task gait speed was 1.86 (0.21) m/s for UB walking and 1.74 (0.25) m/s for NB walking. In NB walking, single task step accuracy was 56.7 (15.4)% and step error magnitude was 1.4 (0.9) cm.

Figure 2 shows the effects of instructed focus and walking task difficulty on absolute measures of walking. Instructed focus influenced gait speed (Fig. 2a), with faster speeds when participants were instructed to focus on walking (walking: 1.84 m/s; cognitive: 1.74 m/s; main effect: $P = 0.006$). Task difficulty also influenced gait speed, with faster gait speeds in the UB condition (UB: 1.82 m/s; NB: 1.77 m/s; main effect: $P = 0.008$). There was a significant interaction between instructed focus and task difficulty, with a larger effect of instructions for UB walking ($P = 0.008$). An analysis of relative change using gait speed DTEs showed a slightly different pattern of effects. The effect of instructed focus remained significant (walking: 0.7%; cognitive: −1.8%; main effect: $P = 0.02$), but there was no main effect of task difficulty on gait speed DTEs (main effect: $P = 0.27$). The significant interaction between instructed focus and task difficulty remained ($P = 0.02$), with a greater effect of instructed focus for UB walking.

Instructed focus influenced absolute step accuracy during NB walking, with greater step accuracy in the walking focus condition (Fig. 2b; walking: 51.4%; cognitive: 45.1%; main effect: $P = 0.05$). Step error magnitudes were small in both conditions, with a trend toward smaller errors with the walking focus (walking: 1.2 cm; cognitive: 1.5 cm; $P = 0.06$). With instructions to focus on walking, step width was narrower (walking: 7 cm; cognitive: 8 cm; $P = 0.03$), but step width variability did not differ (walking: 23.7%; cognitive: 21.8%; $P = 0.25$). Instructed focus also affected step accuracy DTEs, with smaller step accuracy DTEs in the walking focus condition (walking: −10.6%; cognitive: −21.6%; main effect: $P = 0.05$).

Table 2 shows the effects of instructed focus and task difficulty on secondary spatiotemporal measures. Instructions to focus on walking resulted in longer stride length (walking: 1.65 m; cognitive 1.62 m; $P = 0.01$) and higher cadence (walking: 133 steps/min; cognitive: 131 steps/min; $P = 0.05$). When walking with a UB versus an NB of support, stride length was longer (UB: 1.66 m; NB: 1.61 m; $P < 0.001$) and there was a trend for higher cadence (walking: 134 steps/min; cognitive: 130 steps/min; $P = 0.06$). Step width was wider during UB compared to NB walking (UB: 14 cm; NB: 7 cm; $P < 0.001$). Both step width variability (UB: 14.5%; NB: 22.7%; $P = 0.002$) and stride time variability (UB: 2.0%; NB: 2.4%; $P = 0.02$) were lower during UB versus NB walking.

Trade-offs within tasks

Figure 3 shows trade-offs within tasks using the mAAI. When instructed to focus on the cognitive task, most participants responded by improving response latency, with relatively few changes in response accuracy (Fig. 3a). When instructed to focus on NB walking versus the cognitive task (Fig. 3b), 6 participants improved step accuracy but reduced gait speed, 5 improved speed but reduced accuracy, and 4 improved both gait speed and step accuracy.

Trade-offs between tasks

Figure 4 demonstrates the effects of instructed focus and task difficulty on trade-offs between tasks using a POC. Instructed focus influenced cognitive task DTEs, with larger costs in the walking focus condition (walking: −28.2%; cognitive: −5.6%; main effect: $P < 0.001$). Walking task difficulty did not affect cognitive task DTEs (main effect: $P = 0.18$). There was an interaction between instructed focus and task difficulty for the cognitive task DTEs, with a greater effect of instructions on cognitive task DTEs in the UB walking condition ($P = 0.05$).

Instructed focus influenced walking DTEs, with smaller costs when instructed to focus on walking (walking: −4.6%; cognitive: −12.6%; main effect: $P = 0.008$). Task difficulty also influenced walking DTEs, with smaller costs in the UB walking condition (UB: −1.1%; NB: −16.1%; main effect: $P < 0.001$). There was no interaction between instructed focus and task difficulty on walking DTEs ($P = 0.19$).

Discussion

This study examined the influence of instructed focus and walking task difficulty on dual task performance in healthy young adults. Instructions to focus on one task versus the other influenced both cognitive task and walking performance. Task difficulty affected walking but not cognitive performance, and there was evidence for an interaction between instructed focus and task difficulty.

Our first aim was to determine the effects of instructed focus on dual task performance. As anticipated and consistent with previous research (Siu et al. 2008; Yogev-Seligmann et al. 2010), both cognitive task performance and walking responded to instructed focus.

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Instructions to focus on the cognitive task resulted in shorter response latencies, while instructions to focus on walking resulted in faster gait speed and greater NB step accuracy. For NB walking, trade-offs within the task varied. Different patterns of improvement were observed with instructions to focus on walking—some individuals improved gait speed, some improved step accuracy, and some improved both. With instructions to focus on walking, dual task UB gait speed was 1.88 m/s, while single task UB gait speed was 1.86 m/s. Huxhold et al. (2006) reported improved stance postural control in young adults under some dual versus single task conditions. An improvement in dual compared to single task walking may result from increased arousal under more challenging dual task conditions or may be due to the fact that the cognitive task directed attention away from walking, a postural control task that does not typically require significant attention.

Narrow-base walking was more challenging than UB walking, as evidenced by slower NB gait speed and smaller step width in both single and dual task conditions and larger NB walking DTEs. Step width variability and stride time variability were both greater for NB versus UB walking, though values for these variability measures were similar to those reported previously for healthy adults (Hausdorff et al. 1997; Brach et al. 2005). There was, however, no main effect of walking task difficulty on measures of cognitive performance. This finding contrasts with other research showing cognitive task declines with more difficult postural or walking tasks (Brown et al. 1999, 2005; Shumway-Cook and Woollacott 2000; Rapp et al. 2006). Because a variety of cognitive tasks were used in these studies (e.g., simple reaction time, choice reaction time, working memory), characteristics of the cognitive task could contribute to the observed differences. In fact, different cognitive tasks have been shown to have different effects on stance postural control in healthy young (Kerr et al. 1985; Woollacott and Vander Velde 2008) and older adults (Huxhold et al. 2006).

Our second aim was to determine whether there was an interaction between instructed focus and task difficulty. The interaction between instructed focus and task difficulty for cognitive task DTEs suggests that walking task difficulty modifies the ability to shift performance of a cognitive task in response to instructions. When instructed to focus on walking, cognitive task DTEs were in excess of −25% for both UB and NB walking. In contrast, when instructed to focus on the cognitive task, DTEs were −1.8% for UB walking and −9.4% for NB walking. Thus, the effect of walking task difficulty on cognitive performance appears to be influenced by attentional focus.

Instructed focus influenced both gait speed and cognitive task DTEs more during UB versus NB walking for healthy young adults. These results suggest that some minimum amount of cognitive resources may be necessary for more challenging mobility tasks, thus limiting the ability to shift attention and task performance under more difficult walking conditions. In an early paper on the posture-first hypothesis, Shumway-Cook et al. (1997) proposed a modification to the original posture-first hypothesis, suggesting that “allocation of attention during the performance of concurrent tasks is complex, depending on many factors including the nature of both the cognitive and postural task, the goal of the subject, and the instructions.” Specifically, they noted that in high-risk situations, postural control would be the first priority for the allocation of attentional resources, but in low-risk situations, attention allocation may be more flexible. The current results demonstrate an interaction between postural task difficulty and instructed focus for several variables, which supports the idea that the ability to flexibly modify dual task performance in response to instructions decreases under conditions of increased postural challenge.

Importantly, the ability to accurately assess the singular and interactive effects of instructed focus and task difficulty was dependent on the examination of trade-offs both within each task and between tasks. The mAAI was used to examine within-task trade-offs that contribute to performance improvements in response to instructed focus. Cognitive task improvements were consistently achieved through reduced response latency, but for NB walking, different strategies were reflected by trade-offs of gait speed and step accuracy. The POC was used to examine trade-offs between walking and the cognitive task and to demonstrate the influence of instructions and task difficulty on interference between these tasks. Thus, the POC can provide a framework for examining how individual (e.g., age, neurologic pathology), environmental (e.g., surface conditions), and task (e.g., task difficulty) characteristics affect dual task interference and performance in future research.

There are a number of limitations in this study. First, several aspects of the walking task could potentially influence the results and could therefore limit the ability to generalize these findings. The use of a narrow-base path versus a narrow balance beam (Gage et al. 2003) allowed trade-offs between gait speed and step accuracy. We chose to use a path because this protocol could be used safely with a variety of populations. Participants walked with arms crossed in order to minimize the obstruction of markers at the hip, and this potentially affected stability during walking (particularly NB walking). Also, participants were instructed to walk as quickly as they safely could rather than at a self-selected speed. These methodological choices would have acted to maximally challenge postural control, potentially resulting in greater attentional demands of walking. The functional application of this research may be limited because many factors can affect dual task performance. Interactions between factors like instructions and task difficulty are complex and may vary with the combination of tasks executed. While two levels of walking task difficulty were examined, only one level of cognitive task difficulty was used. Future research should examine the effects of cognitive task difficulty on attention allocation and task performance under dual task conditions. However, despite these limitations, the frameworks presented here may prove useful for future research examining factors that affect dual task performance.

In summary, this study examined the effects of instructed focus and task difficulty on concurrent walking and cognitive task performance in healthy young adults. Instructed focus influenced both the cognitive task and walking, while task difficulty influenced only the walking task. For healthy young adults, there was some evidence for an interaction between task difficulty and instructed focus. The mAAI examined within-task trade-offs, and the POC examined between-task trade-offs. Together, these provide a framework for measuring and interpreting changes in dual task performance. An improved understanding of dual task performance has important clinical implications for the assessment of dual task deficits associated with aging and neurologic pathology and the development of treatments designed to alleviate these deficits.

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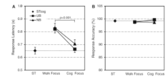

Fig. 1.

The effect of instructed focus and walking task difficulty on cognitive task response latency (**a**) and response accuracy (**b**). *Symbols* represent means for cognitive task performance in the single task (ST) condition (*diamonds*) and under usual-base (*squares*) and narrow-base (*triangles*) walking dual task conditions. *Bars* represent standard errors (*note* standard errors for response accuracy were <1% in all cases). *ST* single task condition, *walk focus* walking focus condition, *cog focus* cognitive task focus condition

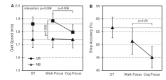

Fig. 2.

The effect of instructed focus and walking task difficulty on usual and narrow-base gait speed (**a**), and the effect of instructed focus on narrow-base step accuracy (**b**). *Symbols* represent means for walking under usual-base (*squares*) and narrow-base (*triangles*) walking conditions. *Bars* represent standard errors. *ST* single task condition, *walk focus* walking focus condition, *cog focus* cognitive task focus condition

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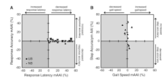

Fig. 3.

Modified attention allocation index (mAAI) values to examine within-task trade-offs in response to instructions for each individual. Cognitive task (response latency and response accuracy) mAAI values under usual-base and narrow-base walking conditions (**a**). In response to instructions to focus on walking versus the cognitive task, participants primarily decreased response latency, with minimal changes in response accuracy. Walking (gait speed and step accuracy) mAAI values under the narrow-base condition (**b**). In response to instructions to focus on walking versus the cognitive task, participants showed a variety of within-task trade-offs. Some participants increased step accuracy and decreased gait speed, some decreased step accuracy and increased gait speed, and some increased both gait speed and step accuracy

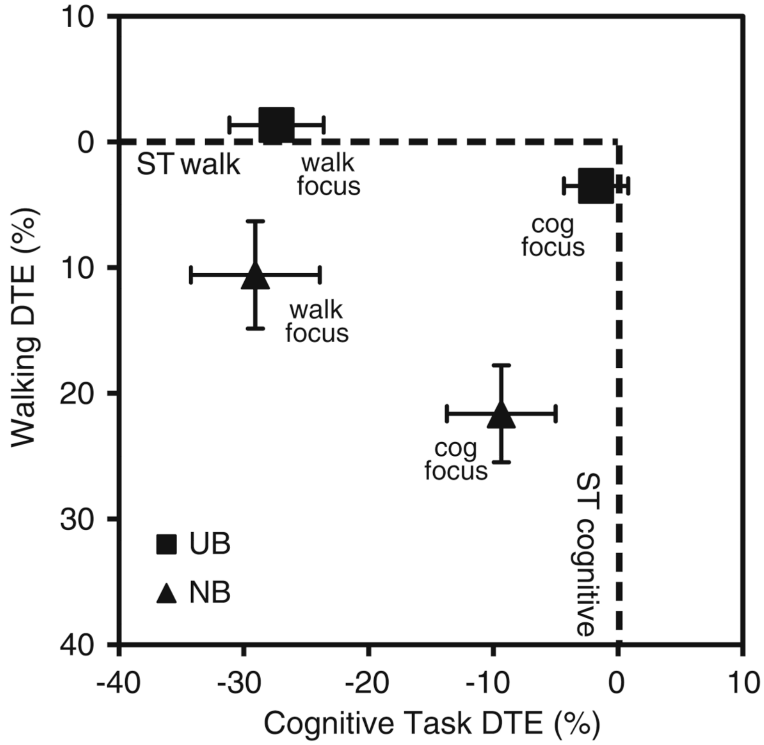

Fig. 4.
Performance operating characteristic framework showing the effects of instructed focus and task difficulty. Single task performance is represented by the *dashed lines*. The dual task effects for each point are reflected in the distance from each point to the line representing single task performance. *Points* represent means and *bars* represent standard errors (*note* standard errors for UB walking ≤1% in both cases)

Table 1

Effects of dual task performance, instructed focus, and task difficulty on absolute and relative measures of cognitive task and walking performance

	Usual-base walking			Narrow-base walking		
	Single task	Dual task		Single task	Dual task	
		Walking focus	Cognitive focus		Walking focus	Cognitive focus
Walking						
Gait speed (m/s)	1.86 (0.21)	1.88 (0.22)	1.80 (0.22)	1.74 (0.25)	1.74 (0.26)	1.74 (0.26)
Gait speed DTE (%)	–	1.4 (3.9)	−3.5 (3.4)	–	0.0 (3.6)	−0.1 (4.4)
Step accuracy (%)	–	–	–	56.7 (15.4)	51.4 (19.8)	45.1 (15.9)
Step accuracy DTE (%)	–	–	–	–	−10.6 (17.7)	−21.6 (15.0)
Walking DTE (%)	–	1.4 (3.9)	−3.5 (3.4)	–	−10.6 (16.5)	−21.6 (14.9)
Cognitive task						
Response latency (s)	0.65 (0.10)	0.82 (0.12)	0.66 (0.10)	0.65 (0.10)	0.83 (0.14)	0.71 (0.13)
Response latency DTE (%)	–	−27.0 (14.6)	−2.2 (9.6)	–	−28.7 (19.9)	−8.8 (16.3)
Response accuracy (%)	99.2 (1.1)	98.8 (2.3)	99.7 (0.9)	99.2 (1.1)	98.8 (2.4)	98.7 (2.1)
Response accuracy DTE (%)	–	−0.4 (2.1)	0.5 (1.1)	–	−0.4 (2.8)	−0.6 (2.1)
Cognitive task DTE (%)	–	−27.4 (14.6)	−1.8 (10.0)	–	−29.1 (20.0)	−9.4 (16.7)

Values represent the mean (standard deviation). *DTE* dual task effects. Positive DTE values indicate an improvement under dual compared to single task conditions. Negative DTE values indicate a decrement under dual compared to single task conditions

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Table 2

Effects of dual task performance, instructed focus, and task difficulty on secondary spatiotemporal measures

	Usual-base walking			Narrow-base walking		
	Single task	Dual task		Single task	Dual task	
		Walking focus	Cognitive focus		Walking focus	Cognitive focus
Stride length (m)	1.68 (0.15)	1.68 (0.15)	1.63 (0.15)	1.64 (0.17)	1.61 (0.15)	1.61 (0.16)
Cadence (steps/min)	134 (15)	135 (16)	132 (16)	129 (17)	130 (18)	130 (18)
Step width (cm)	14 (2)	14 (2)	14 (2)	7 (2)	7 (2)	8 (2)
Step width variability (%)	14.6 (4.7)	15.7 (6.0)	13.3 (4.5)	23.0 (8.3)	23.7 (9.5)	21.8 (9.4)
Stride time variability (%)	3.8 (2.7)	2.1 (0.7)	2.0 (0.5)	3.6 (1.6)	2.5 (1.2)	2.2 (0.6)

Values represent the mean (standard deviation)