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Task-prioritization and balance recovery strategies used by young healthy adults during dual-task walking

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ABSTRACT

Background: Maintaining dynamic balance is an essential task during walking, with foot-placement playing a critical role. Dual-task studies analyzing steady-state walking with cognitive loads have found healthy adults prioritize cognitive task performance at the expense of maintaining control of their balance. However, few studies have focused on the influence of cognitive loads on more difficult motor tasks, such as walking with unexpected foot-placement perturbations. Individuals often recover from a loss of balance using an ankle or hip strategy; however, how cognitive loads affect these balance recovery strategies remains unknown.

Research question: How do individuals prioritize cognitive resources and does the balance recovery strategy used change following mediolateral foot-placement perturbations during steady-state walking when performing cognitive tasks of increasing difficulty?

Methods: Fifteen young healthy adults walked during unperturbed and perturbed conditions with increasing cognitive loads (no cognitive load, attentive listening, spelling short words backwards and spelling long words backwards). No specific task-prioritization instructions were given. Medial and lateral foot-placement perturbations were applied prior to heel-strike during random steps.

Results: Cognitive performance decreased between the unperturbed and perturbed conditions. While balance control decreased during perturbed relative to unperturbed walking, the additional cognitive load had little effect on balance control during the perturbations. Lastly, the balance recovery strategy used, as measured by peak joint moments at the ankle and hip, was unaffected by the additional cognitive loads.

Significance: Individuals appear to prioritize their balance control over cognitive performance when experiencing foot-placement perturbations and do not change their balance recovery strategy with the addition of a cognitive load. These results highlight the flexibility of task-prioritization in young adults and provide a foundation for future studies analyzing neurologically impaired populations.

1. Introduction

Maintaining dynamic balance during walking is critical to prevent falling and becomes more challenging when performing an additional cognitive task [1]. Dual-task (DT) studies, which require participants to perform multiple tasks simultaneously, often combine steady-state walking with an additional cognitive task [e.g., 2,3]. Some studies extend this paradigm to more challenging motor tasks, such as split belt gait adaptation [e.g., 4], obstacle avoidance [e.g., 5], perturbed standing [e.g.,6] and perturbed walking [e.g., 7,8]. Foot-placement plays a critical role in balance control [9]; however, few studies have examined foot-placement perturbations in the context of a DT. Some DT studies found that individuals prioritize the cognitive task performance at the expense of their balance control [3,10,11]. However, others have found that individuals prioritize their balance control at the expense of cognitive performance [12], or have enough cognitive resources to maintain both balance and cognitive performance [13]. The differences in these studies highlight how DT performance is highly dependent on the difficulty of the cognitive or motor task and available resources [3]. However, it remains unclear how cognitive performance and balance control are prioritized when confronted with a more challenging motor task such as walking with foot-placement perturbations. Understanding how young healthy adults prioritize cognitive resources when faced with challenging cognitive and motor tasks would provide a benchmark for

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future studies in populations with cognitive and locomotor impairments.

Maintaining frontal plane balance requires more active control than in the transverse or sagittal planes [14], and DT effects are most often seen in the frontal plane [11,15–17]. Thus, frontal plane balance could be affected by an additional cognitive load while experiencing a mediolateral (ML) foot-placement perturbation. Healthy adults often compensate for a loss of balance due to unexpected ML perturbations with a variety of strategies [18,19]. For example, a lateral ankle strategy uses an inversion moment that quickly moves the center of pressure to the outer limit of the foot to compensate for medial perturbations, but is constrained by the surface area of the foot. A hip strategy uses a hip abduction moment to assist in maintaining balance by counteracting the gravitational moment [18,20]. Any larger adjustments would need to occur on subsequent steps [18]. Previous studies analyzing DTs with perturbations have largely focused on quiet standing [6,21–24], and the few that have studied walking include either walking over a soft surface [7,25] or walking with translating surfaces [13]. Further, no study has analyzed the influence of a cognitive load on the strategies used to control balance in response to ML foot-placement perturbations, which would provide additional insight into the task-prioritization involved in maintaining frontal plane balance.

The purpose of this study was to assess how healthy individuals prioritize cognitive resources and identify the balance recovery strategy used in response to ML foot-placement perturbations while performing cognitive tasks of increasing difficulty. We hypothesize that as the cognitive load increases from attentive listening to spelling short and then long words backwards, the cognitive load will require more attentional resources, thus causing a delay in response time to the perturbation. Furthermore, we expect this delay will cause individuals to use the quicker ankle strategy rather than the hip strategy during recovery from the perturbation with more challenging cognitive loads in order to maintain their balance.

2. Methods

2.1. Data collection

Fifteen young healthy adults (6 males; age: 25 ± 4 years; height: 175 ± 11 cm; mass: 67 ± 11 kg) who were fluent in English were recruited from the local community. All subjects provided informed written consent prior to participating in this institutionally approved protocol. All participants were free from any musculoskeletal or neuromuscular injuries. Data collection trials consisted of 30–45 s of steady-state and perturbed treadmill walking performed at a fixed speed of 1.0 m/s and their self-selected walking speed, which resulted in two steady-state and two perturbed trials for each cognitive load. Trial duration was determined by when the random perturbations were applied. To determine their self-selected walking speed, three trials of 10-meter overground walking at their “comfortable, typical walking speed” were performed and averaged. Three-dimensional full-body kinematic data were collected at 120 Hz using 65 reflective markers with a 10-camera motion capture system (Vicon, Oxford, UK). Three-dimensional ground reaction force (GRF) data were collected at 960 Hz using a split-belt instrumented treadmill (Motek, Amsterdam, Netherlands).

Participants performed a cognitive single-task (ST) control trial (spelling-while-standing) consisting of three short words and three long words, and then steady-state unperturbed and perturbed treadmill walking trials at both speeds. Walking trials were completed with four different cognitive loads: a ST no load walking condition (no load), and three DT walking conditions (attentive listening (listen), spelling short 5-letter words backwards (short words) and spelling long 10-letter words backwards (long words)). Spelling responses were recorded through a microphone. Walking and cognitive load conditions, speeds and the order of the words presented were randomized.

2.2. Cognitive loads

Participants wore noise-canceling headphones for all trials to prevent acoustic distractions. For the attentive listening trials, participants were instructed to listen carefully to the story they heard through the headphones because they would be quizzed on what they heard after the trials finished. However, this instruction was only given to ensure they listened carefully, and no other task-prioritization instructions were given.

During the spelling conditions, participants were instructed to spell each word backwards as quickly and accurately as possible. Thirty 5-letter and 10-letter words commonly used in everyday vernacular were selected from the English dictionary, and each spelling trial consisted of only short or long words as the cognitive load. Participants heard each pre-recorded word through the headphones with the next word playing immediately after they spelled the previous word, completing as many words as possible.

2.3. Perturbations

During each perturbed walking trial, a custom pneumatic device applied two lateral and two medial perturbations to the left ankle just before heel-strike at random but non-consecutive steps throughout the trial [19]. Briefly, the perturbations were generated by a valve releasing compressed air at the ankle 140 ms before heel-strike, producing a force of approximately 15 N that altered foot-placement medially or laterally (see Appendix and ref [19] for more detail).

2.4. Data analysis

Marker and force plate data were low-pass filtered at 6 Hz and 15 Hz, respectively, using a fourth-order Butterworth filter. A 13-segment inverse dynamics model was created for each subject using Visual 3D (C-Motion, Germantown, MD). The segments included in the model were the head, torso and pelvis, and left and right upper arm, forearm, thigh, shank and foot. Dynamic balance was quantified by analyzing frontal plane whole-body angular momentum (H), which was calculated by summing the angular momentum of each body segment about the whole-body center of mass. H was normalized by subject mass, height and walking speed. Balance control was quantified as the range of H (H_R), defined as the difference in the highest and lowest peaks of H over the gait cycle, where lower H_R indicates more tightly controlled balance [26]. Steps where the participant’s foot landed on the incorrect force plate were identified and removed from the kinetic analyses. Joint moments at the ankle and hip were normalized by subject mass and moment impulses were calculated as the time integral of the joint moment over the gait cycle and over each of the four regions of stance (first double support, first and second half of single leg stance, second double support). Recorded audio was examined to determine correct response rate (correct letters per second) as the measure of cognitive performance.

2.5. Statistics

A linear mixed effects model was used to assess differences in the outcome measures (H_R, peak ankle inversion moment, peak hip abduction moment, percent of the gait cycle when the peak moments occurred, ankle and hip moment impulses and cognitive response) between the unperturbed walking and perturbed DT walking conditions. Separate models were created for the medial and lateral perturbations over the entire gait cycle and within four regions of stance (first double support, first and second half of single leg stance, second double support). The mixed effects model found no differences in outcome measures between the self-selected (group average of 1.3 m/s) and standardized (1.0 m/s)

Table 1
Cognitive performance (mean ± 1 standard deviation). Bold indicates a significant difference from the steady-state dual-task of the corresponding length ($p < 0.05$).

	Single-Task		Steady-State Dual-Task		Perturbed Dual-Task	
	Short	Long	Short	Long	Short	Long
Correct response rate (letters/s)	1.91 ± 0.5	1.02 ± 0.5	1.87 ± 0.6	1.04 ± 0.4	**1.67 ± 0.4**	**0.90 ± 0.3**

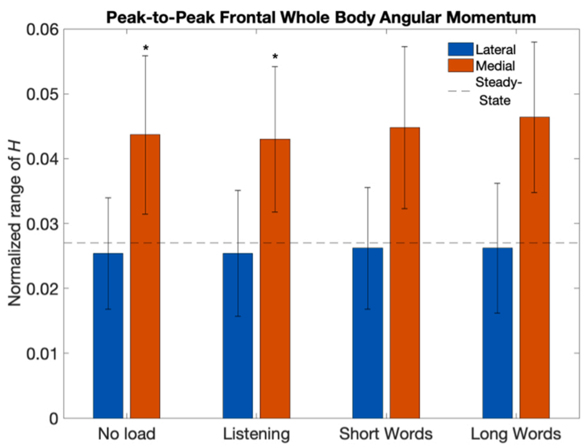

Fig. 1. Peak-to-peak differences in frontal plane whole-body angular momentum (H_R, normalized by height, mass and speed of each individual) for the no load and three dual-task conditions. The horizontal dashed line represents H_R for steady-state unperturbed walking. * indicates a significant difference from the long word DT with a medial foot-placement perturbation ($p < 0.05$). Error bars represent ± 1 standard deviation.

walking speed conditions, and therefore were pooled for further statistical analysis. The walking conditions (level of cognitive load and perturbation) were the fixed effects, and the study subjects were the random effects. If the linear mixed effects model revealed significant effects, Tukey HSD post-hoc tests were performed to identify pairwise differences between the DT conditions. The significance level was set at $p < 0.05$. All statistical analyses were performed using the statistical toolbox in MATLAB (Mathworks, Natick, MA).

3. Results

3.1. Cognitive load

Spelling performance did not change between the ST and DT conditions (steady-state short and long words $p = 0.994$, perturbed short and long words $p = 0.156$) (Table 1). However, within the DT conditions, correct response rate decreased between the steady-state unperturbed and perturbed DT for both the short and long word conditions ($p = 0.003$ for both). In all conditions, individuals performed worse in the long word than in the short word condition with a lower correct response rate ($p < 0.001$).

3.2. Balance control

Frontal plane H_R was higher for the medial perturbations compared to the lateral perturbations and steady-state unperturbed walking (Fig. 1). The only significant effect on frontal plane H_R when adding a cognitive load was a slight increase between the no load and long word condition ($p = 0.045$) and between the listening and long word condition for the medial perturbation ($p = 0.006$) (Fig. 1).

3.3. Lateral ankle strategy

The addition of a cognitive load did not affect the ankle inversion moment peaks or timing over the gait cycle for either the lateral

Table 2
Lateral perturbations (mean ± 1 standard deviation). a-f indicate pairwise Tukey post-hoc comparisons performed when the linear mixed effect model produced significant interactions ($p < 0.05$). a = between no load and listening DT, b = between no load and short words DT, c = between no load and long words DT, d = between listening DT and short words DT, e = between listening DT and long words DT, f = between short words DT and long words DT. Bold indicates significance.

Variable	Condition	Mean ± SD	Linear Mixed Effects Fixed *p*-value	Comparisons	*p*-value
H_R	Steady-State	0.0270 ± 0.008	**0.021**	a	0.999
	No Load	0.0254 ± 0.009		b	0.839
	Listen DT	0.0254 ± 0.010		c	0.843
	Short words DT	0.0262 ± 0.009		d	0.698
	Long words DT	0.0262 ± 0.010		e	0.716
				f	1.000
Ankle Inversion Moment Impulse (Nms/kg)	Steady-State	-0.63 ± 7.70	< **0.001**	a	0.931
	No Load	-3.76 ± 7.76		b	0.996
	Listen DT	-3.56 ± 7.97		c	0.999
	Short words DT	-4.46 ± 7.49		d	0.767
	Long words DT	-4.72 ± 7.76		e	0.859
				f	0.999
Peak Ankle Inversion Moment (Nm/kg)	Steady-State	-0.209 ± 0.126	**0.005**	a	0.999
	No load	-0.193 ± 0.108		b	0.998
	Listen DT	-0.194 ± 0.102		c	0.975
	Short words DT	-0.207 ± 0.104		d	0.976
	Long words DT	-0.214 ± 0.118		e	0.907
				f	0.999
Hip Abduction Moment Impulse (Nms/kg)	Steady-State	-47.79 ± 16.77	**0.002**	a	0.985
	No Load	-46.47 ± 13.07		b	0.990
	Listen DT	-45.07 ± 10.44		c	0.998
	Short words DT	-45.16 ± 10.88		d	1.00
	Long words DT	-46.83 ± 11.43		e	0.999
				f	1.00
Peak Hip Inversion Moment (Nm/kg)	Steady-State	0.924 ± 0.226	0.395		
	No Load	0.975 ± 0.229			
	Listen DT	0.956 ± 0.212			
	Short words DT	0.929 ± 0.205			
	Long words DT	0.990 ± 0.229			

Table 3
Medial perturbations (mean ± 1 standard deviation). a-f indicate pairwise Tukey post-hoc comparisons performed when the linear mixed effect model produced significant interactions ($p < 0.05$). a = between no load and listening DT, b = between no load and short words DT, c = between no load and long words DT, d = between listening DT and short words DT, e = between listening DT and long words DT, f = between short words DT and long words DT. Bold indicates significance.

Variable	Condition	Mean ± SD	Linear Mixed Effects Fixed *p*-value	Comparisons	*p*-value
H_R	Steady-State	0.0270 ± 0.008	**0.021**	a	0.969
	No Load	0.0437 ± 0.010		b	0.806
	Listen DT	0.0430 ± 0.010		c	**0.045**
	Short words DT	0.0448 ± 0.010		d	0.411
	Long words DT	0.0464 ± 0.010		e	**0.006**
				f	0.471
Ankle Inversion Moment Impulse (Nms/kg)	Steady-State	-0.63 ± 7.70	0.834		
	No Load	0.81 ± 9.79			
	Listen DT	0.26 ± 7.24			
	Short words DT	0.52 ± 8.79			
	Long words DT	-1.36 ± 11.11			
Peak Ankle Inversion Moment (Nm/kg)	Steady-State	-0.209 ± 0.126	**0.003**	a	0.956
	No Load	-0.210 ± 0.099		b	0.785
	Listen DT	-0.219 ± 0.116		c	0.313
	Short words DT	-0.229 ± 0.122		d	0.991
	Long words DT	-0.238 ± 0.173		e	0.736
				f	0.949
Hip Abduction Moment Impulse (Nms/kg)	Steady-State	-47.79 ± 16.77	< **0.001**	a	0.523
	No Load	-44.60 ± 15.60		b	0.987
	Listen DT	-41.61 ± 12.39		c	0.986
	Short words DT	-43.55 ± 13.54		d	0.845
	Long words DT	-46.27 ± 16.94		e	0.229
				f	0.850
Peak Hip Abduction Moment (Nm/kg)	Steady-State	0.924 ± 0.226	**< 0.001**	a	0.993
	No Load	0.731 ± 0.252		b	0.815
	Listen DT	0.730 ± 0.249		c	0.997
	Short words DT	0.762 ± 0.273		d	0.557
	Long words DT	0.736 ± 0.288		e	0.939
				f	0.947

(Table 2) or medial (Table 3) perturbations (Fig. 2, $p > 0.05$). There were also no differences in the ankle inversion moment impulse across the different cognitive loads in any of the four regions of stance.

3.4. Hip strategy

The addition of a cognitive load also did not affect the peak hip abduction moment or timing for either the lateral (Table 2) or the medial (Table 3) perturbations (Fig. 3, $p > 0.05$). There were also no differences in the hip abduction moment impulse across the different cognitive loads in any of the four regions of stance.

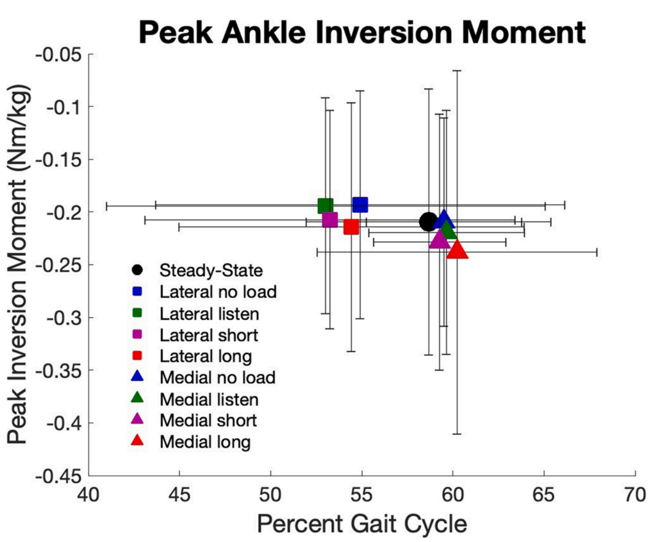

Fig. 2. Peak ankle inversion moment for the lateral and medial perturbed conditions during the four cognitive loads (no load, listening and spelling short and long words backwards) and where in the gait cycle the peaks occurred. The gait cycle is defined from the perturbed foot heel-strike to heel-strike. Positive is inversion and negative is eversion. Error bars represent ± 1 standard deviation.

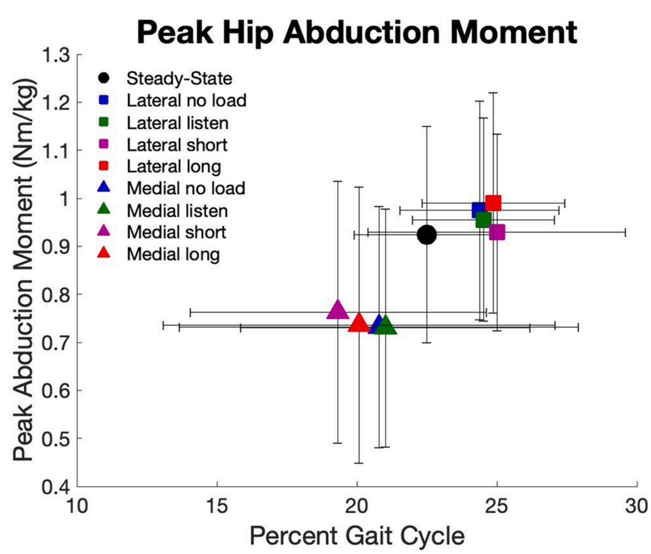

Fig. 3. Peak hip abduction moment for the lateral and medial perturbed conditions during the four cognitive loads (no load, listening and spelling short and long words backwards) and where in the gait cycle the peaks occurred. The gait cycle is defined from the perturbed foot heel-strike to heel-strike. Positive is adduction and negative is abduction. Error bars represent ± 1 standard deviation.

4. Discussion

This study assessed how young healthy adults prioritize cognitive resources to recover their balance when presented with a foot-placement perturbation during DT walking conditions and whether the DT influences the balance recovery strategy used. Contrary to our hypothesis, there was no difference in the ankle or hip response time to the perturbation with increased cognitive loads, and therefore individuals did not need to use the faster ankle strategy. The cognitive loads did not cause a change in the ankle or hip peak moment or timing of the peak moment during stance (Fig. 2 & 3). Furthermore, cognitive performance decreased between steady-state and perturbed walking, suggesting that participants switched their attention to focus more on balance control when experiencing unexpected changes to foot-placement.

4.1. Cognitive performance

Spelling words backwards has been used in DT paradigms in young and older healthy adults [11,27,28] and individuals post-concussion [29], as it is a challenging cognitive task that can produce cognitive-motor interference during walking [1,11]. When compared to steady-state unperturbed walking, cognitive performance decreased for both the short and long words during the perturbed trials (Table 1). This decrease in cognitive performance is consistent with other work showing that individuals prioritize a motor task over a cognitive task during more challenging walking conditions such as adapting to split-belt treadmill walking [4] and stepping on an uneven surface [7]. However, one study did not observe changes in cognitive performance during varying levels of surface translation perturbation when counting backwards by 7 [13]. This discrepancy is likely due to differences in cognitive task difficulty. For simpler cognitive tasks such as counting backwards, young healthy adults likely have enough cognitive resources to control their balance and maintain their cognitive performance. Therefore, the present finding of decreased cognitive performance suggests that perturbed DTs can cause cognitive-motor interference if the cognitive task is challenging enough to strain the attentional resources of the participants.

4.2. Joint moment responses

Contrary to our hypothesis that the challenging cognitive task would require more attentional resources, and thus cause a delayed response to the perturbation, the cognitive loads did not cause a change in the ankle or hip joint moment patterns for either the medial or lateral perturbations (Fig. 2 & 3). This negligible change in joint moments indicates that the subjects did not change their recovery strategy across the different cognitive loads. However, the variabilities in the peak moments and timing are high due to natural variability in these quantities across strides and subjects, and the moment impulse compounds the variability of these two quantities leading to even greater variability, but these values are consistent with previous studies that have measured these quantities [19]. Furthermore, the differences between the steady-state and perturbed joint moments are consistent with previous studies using similar mediolateral perturbations [19]. These results are consistent with other research showing that cognitive loads do not affect the type of strategy used in recovery during perturbed quiet standing [e.g., 6, 21]. The lack of change in peak joint moments and moment impulses could be due to an automatic reflexive response to the perturbation. However, because cognitive performance decreased, the balance recovery response likely required cognitive resources, and thus subjects focused more on their motor performance than the cognitive load throughout the perturbation to maintain the same recovery strategy regardless of the cognitive load. While other DT perturbed quiet standing studies also did not see changes in recovery strategy, they did find differences within a specific recovery strategy, including changes in timing [24], peak center of pressure [23] and distance between the center of mass and base of support [6] when an additional cognitive load was added. However, these studies were done during quiet standing, and studies of perturbed walking did not see similar changes in motor performance during DT conditions [7,13], consistent with the present results.

4.3. Dynamic balance

Dynamic balance can decrease during DT steady-state walking if the cognitive task is challenging enough, suggesting that individuals focus more on the performance of the cognitive task [11,30]. In the presence of unexpected balance perturbations, the present study found that balance decreases between steady-state and medially perturbed walking with only minor differences in the lateral perturbations. The addition of cognitive loads only decreased balance control slightly between medially perturbed walking without a cognitive task and the long word spelling condition, which was the most challenging DT (Fig. 1). The listening and spelling of short words backwards were likely not challenging enough DTs to produce a change in H_R during the perturbations compared with the no cognitive load condition. We previously showed spelling long words backwards causes a decrease in dynamic balance during steady-state treadmill walking [11]. Therefore, a change in H_R was present during the long word task before the perturbation and could have contributed to the decrease in balance control during the perturbation. However, this decrease in balance control was not seen in the lateral perturbations, which may indicate that the medial perturbation condition demanded more attentional resources due to the difficulty of the task. Regardless, these differences in balance control were small and on the low end of being functionally different [19], and the overall lack of change across the cognitive loads is consistent with other studies that observed no change in balance control during perturbed DT walking [7, 13].

4.4. Limitations

One potential limitation of this study was that the cognitive performance could be influenced by a learning effect across the trials. However, a post-hoc linear regression model applied to the data showed that no participants demonstrated a learning effect resulting in increased accuracy in cognitive performance (average $R\text{-}squared = 0.130$, average p-value $= 0.366$). Another potential limitation was the constraint of the treadmill that prevented participants from altering their walking speed in response to the DT, and thus these results may not hold for overground walking. Finally, due to the study design, cognitive responses could not be separated by the direction of the perturbation. Future work should compare cognitive performance across different types of perturbations.

5. Conclusion

Adding a challenging cognitive load did not affect the timing or magnitude of the recovery strategy used in response to ML foot-placement perturbations in young healthy adults during steady-state walking. A previous study found that during steady-state walking with a challenging cognitive load, young healthy adults focused on their cognitive performance at the expense of their balance control [11], but the current study found that when presented with a foot-placement perturbation that threatens their balance, they switch their attention from the cognitive task to the motor task. This change in task-prioritization results in decreased cognitive performance during the perturbations and little change in balance control across the increasing cognitive loads. These results provide additional insight into task-prioritization and balance recovery strategies used by young healthy adults and provide a benchmark for future studies to determine differences in aging and neurologically impaired populations.

Competing interests

The authors declare that they have no competing interests.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.gaitpost.2022.04.010.

References

[1] J.H. Hollman, F.M. Kovash, J.J. Kubik, R.A. Linbo, Age-related differences in spatiotemporal markers of gait stability during dual task walking, Gait Posture 26 (2007) 113–119, https://doi.org/10.1016/j.gaitpost.2006.08.005.
[2] G. Ebersbach, M.R. Dimitrijevic, W. Poewe, Influence of concurrent tasks on gait: a dual-task approach, Percept. Mot. Skills 81 (1995) 107–113, https://doi.org/10.2466/pms.1995.81.1.107.
[3] G. Yogev-Seligmann, J.M. Hausdorff, N. Giladi, Do we always prioritize balance when walking? Towards an integrated model of task prioritization, Mov. Disord. 27 (2012) 765–770, https://doi.org/10.1002/mds.24963.
[4] D.C. Hinton, D. Conradsson, L. Bouyer, C. Paquette, Does dual task placement and duration affect split-belt treadmill adaptation? Gait Posture 75 (2020) 115–120, https://doi.org/10.1016/j.gaitpost.2019.10.005.
[5] M. Yamada, H. Tanaka, S. Mori, K. Nagai, K. Uemura, B. Tanaka, T. Aoyama, N. Ichihashi, Fallers choose an early transfer gaze strategy during obstacle avoidance in dual-task condition, Aging Clin. Exp. Res. 23 (2011) 316–319, https://doi.org/10.1007/BF03337757.
[6] L.A. Brown, A. Shumway-Cook, M.H. Woollacott, Attentional demands and postural recovery: the effects of aging, J. Gerontol. Ser. A 54 (1999) M165–M171, https://doi.org/10.1093/gerona/54.4.M165.
[7] F. Mersmann, S. Bohm, S. Bierbaum, R. Dietrich, A. Arampatzis, Young and old adults prioritize dynamic stability control following gait perturbations when performing a concurrent cognitive task, Gait Posture 37 (2013) 373–377, https://doi.org/10.1016/j.gaitpost.2012.08.005.
[8] J.O. Nnodim, H. Kim, J.A. Ashton-Miller, Dual-task performance in older adults during discrete gait perturbation, Exp. Brain Res. 234 (2016) 1077–1084, https://doi.org/10.1007/s00221-015-4533-0.
[9] S.A. Roelker, S.A. Kautz, R.R. Neptune, Muscle contributions to mediolateral and anteroposterior foot placement during walking, J. Biomech. 95 (2019), 109310, https://doi.org/10.1016/j.jbiomech.2019.08.004.
[10] P. Plummer-D′Amato, L.J.P. Altmann, D. Saracino, E. Fox, A.L. Behrman, M. Marsiske, Interactions between cognitive tasks and gait after stroke: a dual task study, Gait Posture 27 (2008) 683–688, https://doi.org/10.1016/j.gaitpost.2007.09.001.
[11] G.H. Small, L.G. Brough, R.R. Neptune, The influence of cognitive load on balance control during steady-state walking, J. Biomech. 122 (2021), https://doi.org/10.1016/j.jbiomech.2021.110466.
[12] R. Tisserand, S. Armand, G. Allali, A. Schnider, S. Baillieul, Cognitive-motor dual-task interference modulates mediolateral dynamic stability during gait in post-stroke individuals, Hum. Mov. Sci. 58 (2018) 175–184, https://doi.org/10.1016/j.humov.2018.01.012.
[13] I. Paran, H. Nachmani, I. Melzer, A concurrent attention-demanding task did not interfere with balance recovery function in standing and walking among young adults – an explorative laboratory study, Hum. Mov. Sci. 73 (2020), 102675, https://doi.org/10.1016/j.humov.2020.102675.
[14] C.E. Bauby, A.D. Kuo, Active control of lateral balance in human walking, J. Biomech. 33 (2000) 1433–1440, https://doi.org/10.1016/s0021-9290(00)00101-9.
[15] F. Fallahtafti, J.B. Boron, D.M. Venema, H.J. Kim, J.M. Yentes, Task specificity impacts dual-task interference in older adults, Aging Clin. Exp. Res. (2021), https://doi.org/10.1007/s40520-020-01575-3.
[16] C. Zhang, Q. Song, W. Sun, Y. Liu, Dynamic stability of older adults under dual task paradigm during stair descent, Mot. Control 24 (2020) 113–126, https://doi.org/10.1123/mc.2018-0113.
[17] T. Szturm, P. Maharjan, J.J. Marotta, B. Shay, S. Shrestha, V. Sakhalkar, The interacting effect of cognitive and motor task demands on performance of gait, balance and cognition in young adults, Gait Posture 38 (2013) 596–602, https://doi.org/10.1016/j.gaitpost.2013.02.004.
[18] A.L. Hof, S.M. Vermerris, W.A. Gjaltema, Balance responses to lateral perturbations in human treadmill walking, J. Exp. Biol. 213 (2010) 2655–2664, https://doi.org/10.1242/jeb.042572.
[19] L.G. Brough, G.K. Klute, R.R. Neptune, Biomechanical response to mediolateral foot-placement perturbations during walking, J. Biomech. 116 (2021), 110213, https://doi.org/10.1016/j.jbiomech.2020.110213.
[20] H. Reimann, T. Fettrow, J.J. Jeka, Strategies for the control of balance during locomotion, Kinesiol. Rev. 7 (2018) 18–25, https://doi.org/10.1123/kr.2017-0053.
[21] S.G. Brauer, M. Woollacott, A. Shumway-Cook, The influence of a concurrent cognitive task on the compensatory stepping response to a perturbation in balance-impaired and healthy elders, Gait Posture 15 (2002) 83–93, https://doi.org/10.1016/S0966-6362(01)00163-1.
[22] U. Laessoe, M. Voigt, Anticipatory postural control strategies related to predictive perturbations, Gait Posture 28 (2008) 62–68, https://doi.org/10.1016/j.gaitpost.2007.10.001.
[23] S. Quant, A.L. Adkin, W.R. Staines, B.E. Maki, W.E. McIlroy, The effect of a concurrent cognitive task on cortical potentials evoked by unpredictable balance perturbations, BMC Neurosci. 5 (2004) 18, https://doi.org/10.1186/1471-2202-5-18.
[24] P.J. Patel, T. Bhatt, Attentional demands of perturbation evoked compensatory stepping responses: examining cognitive-motor interference to large magnitude forward perturbations, J. Mot. Behav. 47 (2015) 201–210, https://doi.org/10.1080/00222895.2014.971700.
[25] S. Bohm, F. Mersmann, S. Bierbaum, R. Dietrich, A. Arampatzis, Cognitive demand and predictive adaptational responses in dynamic stability control, J. Biomech. 45 (2012) 2330–2336, https://doi.org/10.1016/j.jbiomech.2012.07.009.
[26] H. Herr, M. Popovic, Angular momentum in human walking, J. Exp. Biol. 211 (2008) 467–481, https://doi.org/10.1242/jeb.008573.
[27] L.V. Bonetti, S.A. Hassan, K.T. Kasawara, W.D. Reid, The effect of mental tracking task on spatiotemporal gait parameters in healthy younger and middle- and older aged participants during dual tasking, Exp. Brain Res. 237 (2019) 3123–3132, https://doi.org/10.1007/s00221-019-05659-z.
[28] J.H. Hollman, K.B. Childs, M.L. McNeil, A.C. Mueller, C.M. Quilter, J.W. Youdas, Number of strides required for reliable measurements of pace, rhythm and variability parameters of gait during normal and dual task walking in older individuals, Gait Posture 32 (2010) 23–28, https://doi.org/10.1016/j.gaitpost.2010.02.017.
[29] D.R. Howell, J. Oldham, C. Lanois, I. Koerte, A.P. Lin, B. Berkstresser, F. Wang, W. P. Meehan III, Dual-task gait recovery after concussion among female and male collegiate athletes, Med. Sci. Sports Exerc. 52 (2020) 1015–1021, https://doi.org/10.1249/MSS.0000000000002225.
[30] C. Oh, L.L. LaPointe, Changes in cognitive load and effects on parameters of gait, Cogent Psychol. 4 (2017), 1372872, https://doi.org/10.1080/23311908.2017.1372872.