

Effect of dual task type on gait and dynamic stability during stair negotiation at different inclinations



Forough Madehkhaksar, Arjan Egges*

Virtual Human Technology Lab, Virtual Worlds Research Group, Information and Computing Science, Utrecht University, Utrecht P.O. Box 80.089, 3508 TB, the Netherlands

ARTICLE INFO

Article history:

Received 20 April 2015

Received in revised form 31 August 2015

Accepted 9 September 2015

Keywords:

Dual-task
Cognitive task
Manual task
Stair gait
Kinematics

ABSTRACT

Stair gait is a common daily activity with great potential risk for falls. Stairs have varying inclinations and people may perform other tasks concurrently with stair gait. This study investigated dual-task interference in the context of complex gait tasks, such as stair gait at different inclinations, a topic about which little is understood. We examined how secondary cognitive and manual tasks interfere with stair gait when a person concurrently performed tasks at different levels of complexity. Gait kinematic data and secondary task performance measures were obtained from fifteen healthy young males while ascending and descending a four-step staircase at three inclinations (17.7°, 29.4°, and 41.5°) as well as level walking. They performed a cognitive task, 'backward digit recall', a manual task, 'carrying a cup of water' and a combination of the two tasks. Gait performance and dynamic stability were assessed by gait speed and whole body center of mass (COM) range of motion in the medial–lateral direction, respectively. No significant effect of the gait task on the cognitive task performance was observed. In contrast, stair walking adversely affected the performance of the manual task compared to level walking. Overall, more difficult postural and secondary tasks resulted in a decrease in gait speed and variation in COM displacement within normal range. Results suggest that COM displacement and gait alterations might be adopted to enhance the stability, and optimize the secondary task performance while walking under challenging circumstances. Our findings are useful for balance and gait evaluation, and for future falls prediction.

© 2015 Elsevier B.V. All rights reserved.

1. Introduction

Falls are a serious clinical problem and can result in severe injuries and even death among older adults [1]. Stair gait is among the most challenging and hazardous types of locomotion, and one of the leading causes of falls-related injuries for the aged population [2]. The risk of fall further increases when people perform tasks like reasoning or carrying an object concurrently with stair gait [3,4].

Two different types of secondary tasks – a cognitive task and a manual task – have been used in dual-task studies [5–7]. Previous studies have reported that undertaking a secondary cognitive task adversely affects gait depending on the task complexity, the population studied and the instruction given regarding to attention prioritisation [8–11]. A manual task, like carrying an

object, is used less often in dual-task studies [5]. Some reports have demonstrated that a manual task, similarly to a cognitive task, adversely affects gait performance [5,12]. Contradictory results have been reported when the manual task requires increased postural stability in order to be correctly performed. In this case, a secondary manual task may lead to extra stabilization rather than perturbation of posture [13,14].

Little is understood about dual-tasking during stair gait. Ojha et al. [3] reported that older adults required more resources than younger adults while performing stair gait concurrently with a verbal task. Recently, Vallabhajosula et al. [4] showed that the impact of performing a cognitive or manual task during stair ascent varies based on the stair ascent phase. Also, they reported that gait and secondary task performance are more strongly associated if the gait task is more challenging. Stair descent is also important to be taken into account, since it has been reported as the most hazardous aspect of stair gait [2]. Finally, gait parameters vary based on stair inclination [15,16] suggesting different levels of complexity of stair gait at different inclinations. To our knowledge, no previous studies investigated manual and cognitive dual-task

* Corresponding author. Tel.: +31 302537588; fax: +31 302532804.

E-mail addresses: f.madehkhaksar@uu.nl (F. Madehkhaksar), j.egges@uu.nl (A. Egges).

URL: <http://vhtlab.nl>

performance during a complex gait task such as stair gait at different inclinations, even though in daily life, people regularly encounter stairs at varying inclinations and concurrently perform additional tasks.

In this study we examined how secondary cognitive and manual tasks interfere with stair gait at varying inclinations for healthy adults. We expected that increasing the complexity of the gait task as well as the type of secondary task would affect both gait and dual-task performance, such that performance of secondary tasks would decline as a compensation to maintain dynamic stability.

2. Methods

2.1. Subjects

Fifteen healthy males (age: 28.5 ± 3.7 years, height: 180.1 ± 7.5 cm, body mass: 74.6 ± 7.5 kg), participated in the experiment. All subjects reported to be free of any musculoskeletal or neurological dysfunction. Ethical approval was obtained from the ethical committee of the Faculty of Social and Behavioural Sciences of Utrecht University (Reference Number: FETC14-020). All subjects gave their informed consent.

2.2. Experimental setup and procedures

Stair gait was performed on an adjustable 4 step staircase at three different inclinations: flat, standard, and steep [15,16] (see Table 1). In the stair gait trials, the participants walked from a starting point about 2 meters away from the staircase on level ground, in order to start ascending the stair from a walk [17,18]. The participants then ascended to the top of the staircase in a step-over manner, turned around, descended the stair and walked back to the starting point. In the level walking trials, the participants walked straight ahead covering the same distance as in the stair walking trials. In all trials, the participants walked barefoot at their comfortable speed, in order to remove the influence of different shoe types.

They performed a cognitive task, backward digit recall (BDR), a manual task, ‘carrying a cup of water’ (CCW) and a combination of two tasks (BDR&CCW) concurrently with the gait task. In BDR, the experimenter read out a sequence of three-digit random numbers at a rate of 40 numbers per minute, and the participants were required to repeat the numbers in reverse order in time to the beat [19]. BDR commenced 10 s before the participants started walking and was performed continuously throughout each trial. In CCW, participants were required to carry a cup of water (0.63 kg) in their dominant hand while trying to keep it vertical. Also, there was a baseline (single gait task) in which no secondary task was performed. Therefore in total, there were four testing combinations for each gait task. Each participant performed three stair walks as well as level walking under each testing condition. The dual-task conditions were randomly presented to the participants. The participants were provided enough time to get familiar with the experimental procedure (see Fig. 1A for an outline).

Table 1
Stair dimensions of the present study.

Stair position	Riser height (cm)	Tread/run (cm)	Inclination (°)
Flat	12	37.5	17.7
Standard	15.5	27.5	29.4
Steep	15.5	17.5	41.5

The performance of BDR was quantified by the ratio between the number of correct recalls and the total number of three-digit numbers presented in each trial. In CCW, two markers were placed on the cup and participants were asked to hold the cup vertically. The task performance task was quantified by measuring the ratio of deviation of the cup in the vertical direction between the first five seconds (in which the subjects were asked not to walk) and the rest of trial.

2.3. Kinematics

Kinematic data was recorded at 100 Hz with a 14-camera three-dimensional motion capture system (Vicon Motion Systems, Oxford, UK). A total of 35 reflective markers were placed at specific anatomical locations in accordance with the Plug-In-Gait marker set (Bodybuilder, Plug in Gait model, Vicon Motion Systems, Oxford, UK). Additionally, one marker was placed on each step edge (see Fig. 1B). Motion data was analyzed using the Vicon Nexus software (version 1.8.5). Kinematic data of the lower limbs and whole body center of mass (COM) were collected using the Vicon Plug-In-Gait model [20].

The gait speed during a single gait cycle was used as a dependent measure to assess gait performance, since the effect of a concurrent cognitive task has shown to be most evident on this variable [9]. The gait speed was measured as the distance traveled by the ankle joint center during the gait cycle divided by the gait cycle time. During level walking, foot contact and toe off were determined according to the coordinate-based algorithm proposed by Zeni et al. [21] using corresponding toe and heel markers. During stair ascent and descent, the stair cycle under analysis was defined according to the literature [22]. During stair gait, foot contact was determined using the method by Grenholm et al. [23]. Event detection was performed with a custom MATLAB R2014a program (MathWorks Inc., Natic, USA).

Maintaining the dynamic stability during gait relies on the ability to control COM motion, thus changes in ML COM motion has been extensively used to detect gait instability [24–27]. Dynamic stability during gait was assessed by the whole body COM range of motion (RoM) in the medial–lateral (ML) direction, i.e. the maximum minus minimum value achieved during the crossing stride. Vertical and anterior–posterior RoM on stairs are constrained, respectively by the stair riser and tread dimensions and were therefore not investigated [26].

2.4. Analysis

Data was analyzed using SPSS for Windows, version 22. A two-factorial repeated measures ANOVA (seven gait task conditions \times four secondary task conditions) including a post hoc Bonferroni test was used to analyze gait speed and ML-RoM as dependent measures. In addition, performance of each secondary task was analyzed using a two-factorial repeated measures ANOVA, separately: gait task (level walking vs. flat stair vs. standard stair vs. steep stair) and secondary task (single vs. BDR&CCW condition).

The data for cup inclination deviation was log-transformed to obtain a normal distribution and to decrease the influence of outliers. The level of significance was set at $p < 0.05$.

3. Results

3.1. Secondary task performance

Table 2 presents the secondary task performance measures. Results for CCW showed a main significant effect of gait task ($p < 0.001$). Cup deviation from the vertical direction during

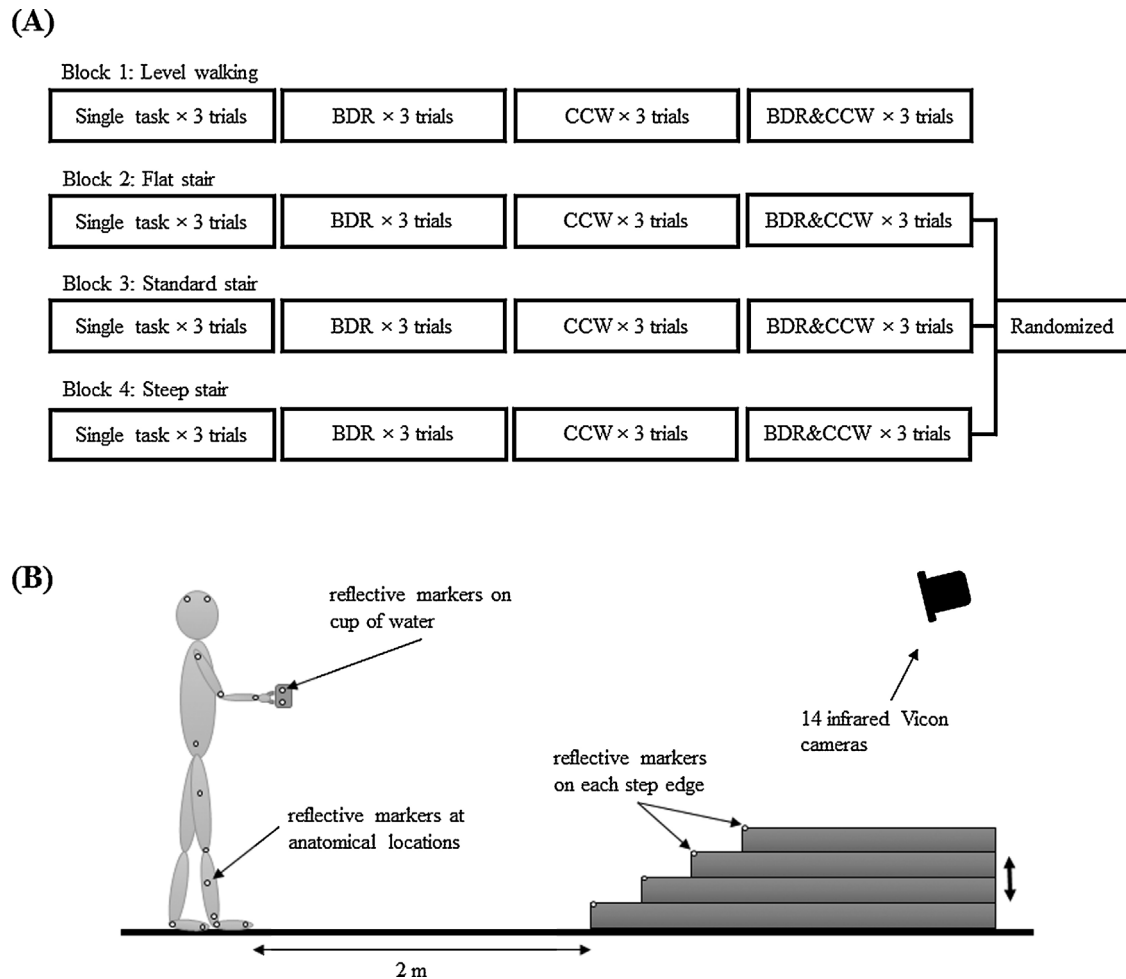


Fig. 1. (A) Block sequences. Trials within each block are randomized. Tasks in block 1 were performed before block 2, 3 and 4. Sequences of block 2, 3 and 4 were randomized. BDR, backward digit recall; CCW, carrying cup of water. (B) Schematic drawing of the staircase (without handrails) and experimental setup. The height of the staircase (riser and tread dimensions) can be adjusted so that the inclination can be varied. Reflective markers were placed at specific anatomical locations in accordance with the Plug-In-Gait marker set.

walking was significantly smaller than stair gait ($p < 0.05$ for all comparisons). In contrast, results for BDR performance showed no main significant effect of gait task. Also, subjects showed no significant difference in the performance of a single secondary task (either BDR or CCW) compared to concurrently performing two secondary tasks (BDR&CCW). A more complex gait task combined with concurrently performed secondary tasks had no effect on either BDR or CCW performance.

3.2. Gait speed

Fig. 2 shows the effects of gait tasks and secondary tasks on gait speed. Gait task significantly affected gait speed ($p < 0.001$) with a significantly slower speed during all stair ascent and descent compared to level walking ($p < 0.001$ for all comparisons). In all

three stair inclinations, gait speed during ascent was significantly slower than descent ($p < 0.001$ for all inclinations). Steeper stairs resulted in a higher gait speed reduction.

The secondary task type showed a significant effect on gait speed ($p < 0.001$). Overall, performing a secondary task decreased gait speed compared to the single task condition. There was an interaction between the gait task by the secondary task effect on gait speed ($p < 0.001$). The effect of a secondary task on gait speed during level walking and stair descent were more obvious than during stair ascent. Gait speed was highest in the single task condition (walking only) and lowest during BDR&CCW compared to the other secondary task conditions. Regardless of the gait task complexity, the difference in gait speed between BDR and CCW was not significant, however participants walked slightly slower during CCW.

Table 2

BDR and CCW secondary task performance in each gait task and secondary task condition (single and concurrent secondary task).

	Single secondary task				BDR&CCW condition			
	Walking	Flat	Standard	Steep	Walking	Flat	Standard	Steep
BDR	0.908 (0.127)	0.956 (0.108)	0.958 (0.106)	0.939 (0.121)	0.924 (0.148)	0.977 (0.072)	0.967 (0.086)	0.951 (0.147)
CCW	0.539 (0.627)	0.607 (0.446)	0.705 (0.734)	0.516 (0.345)	0.529 (0.736)	0.693 (0.592)	0.764 (0.827)	0.639 (0.506)

Values are mean (standard deviation). BDR, backward digit recall; CCW, carrying cup of water. The BDR performance was quantified by the ratio between the number of correct recalls and the total number of three-digit numbers. The CCW performance was quantified by the ratio of deviation of the cup in the vertical direction.

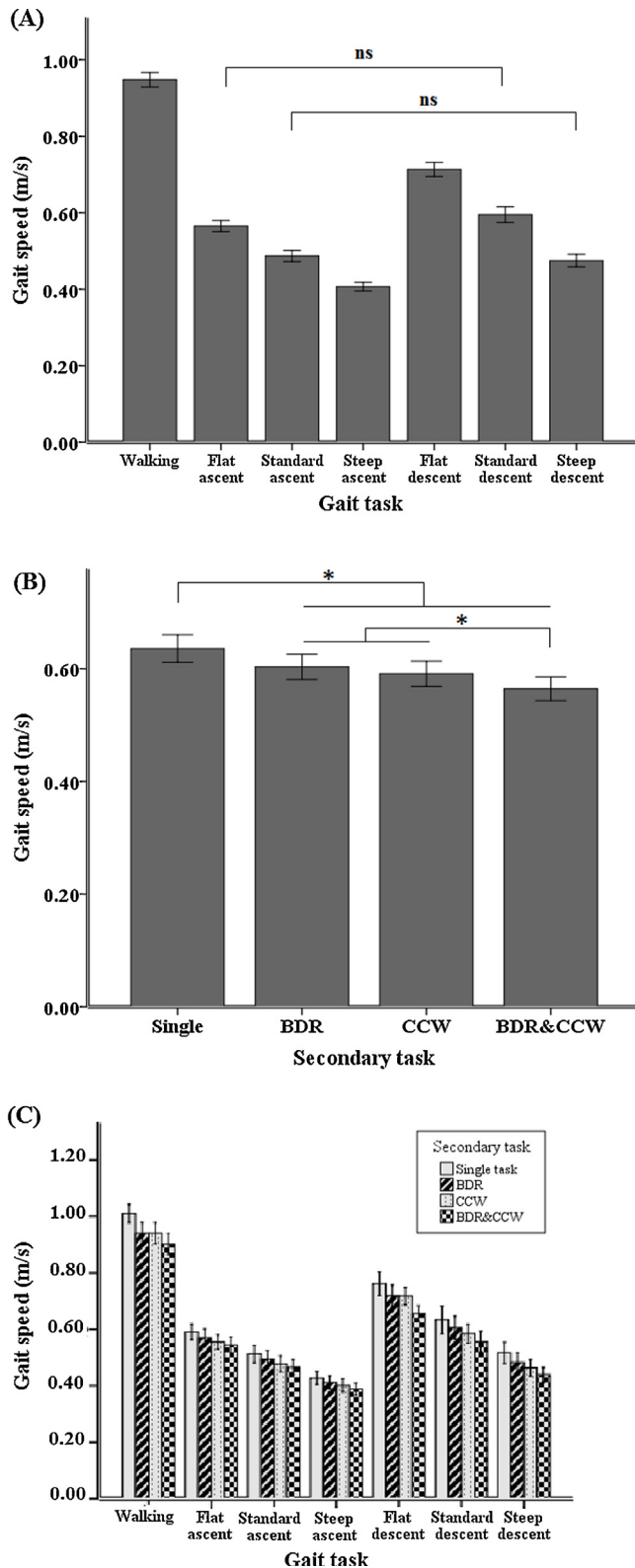


Fig. 2. Gait speed shown as a function of (A) gait task (level walking, flat, standard and steep stair ascent and descent), “ns” indicates non-significant differences ($p > 0.05$) between conditions, i.e. a significant difference is present between all other conditions (B) secondary task (single task, BDR, CCW and BDR&CCW). Significant differences ($p < 0.05$) between the conditions are indicated by *. (C) Gait speed shown as a function of gait task and secondary task. BDR, backward digit recall; CCW, carrying cup of water. Error bars indicate standard error.

3.3. ML-RoM

Fig. 3 shows the effects of gait tasks and secondary tasks on ML-RoM. The secondary task type had a significant effect on ML-RoM ($p < 0.001$). Overall, performing a secondary task increased ML-RoM compared to the single task. However, the only significant difference appeared between the single task and BDR&CCW condition ($p < 0.05$). ML-RoM during CCW was slightly lower than BDR and BDR&CCW but still higher than the single task. BDR&CCW appeared with the highest ML-RoM compared to the other task conditions. There was a significant main effect of the gait task on ML-RoM ($p < 0.001$). However, differences did not appear systematically between the different gait conditions. No interaction effect of gait task by secondary task was observed for ML-RoM.

4. Discussion

This study explored the effect of complex gait tasks, notably stair gait at different inclinations, and different types of secondary tasks on gait and secondary task performance. As we expected, both gait performance and dynamic stability responded to gait task difficulty and secondary task performance. Compared to level walking (gait task baseline) and the single task condition (secondary task baseline), subjects showed an alteration in their gait speed and ML-RoM as a function of gait task complexity as well as type and complexity of the secondary task. The gait task had no effect on the cognitive task performance. In contrast, the manual task performance was affected by gait task complexity. Performing a manual and cognitive task concurrently had no effect on secondary task performance but strongly affected gait speed and ML-RoM.

Previous studies show that cognitive and motor performances decline to a variable extent, depending on the tests being used, when combined in a dual-task scenario. We confirmed this finding when our participants performed a manual task, suggesting that motor control tasks have a direct effect on a secondary manual task, since the resources for the postural control and the manual task performance are both within the motor control system [7]. Therefore, manual task performance declined under more challenging postural conditions in our study. Gait tasks had no effect on the cognitive task performance which is consistent with previous studies [8,10]. In the present work, the absence of any significant decline in cognitive performance during the dual-task test might indicate that no interference was present, as if two totally distinct neuronal control pathways processed the cognitive and motor tasks which is consistent with the literature [11]. This finding contrasts with other research showing that cognitive task performance declines with more difficult postural or walking tasks [28]. Because only one type of cognitive task was used in this study, characteristics of that specific task could contribute to the observed differences. Also, performing BDR and CCW concurrently had no effect on the performance of either task. The multiple resource model posits that processing may need a number of resources [7]. According to this theory, the cognitive and manual tasks in this study might not share common resources, which may explain our findings.

During stair gait, a significant gait speed decrease was observed compared to level walking. More complex gait tasks are more attentionally demanding. Thus, increasing the complexity of gait tasks resulted in decreased gait speed indicating increased motor cost for postural control. However, results for ML-RoM showed no systematic changes as a function of the gait task. ML-RoM was previously used to indicate gait instability [24,27,29]. ML-RoM changes are thought to possibly be due to a reduced ability to confine the COM within a more stable region. However, in our case, the mean values for ML-RoM appeared normal (ranging from

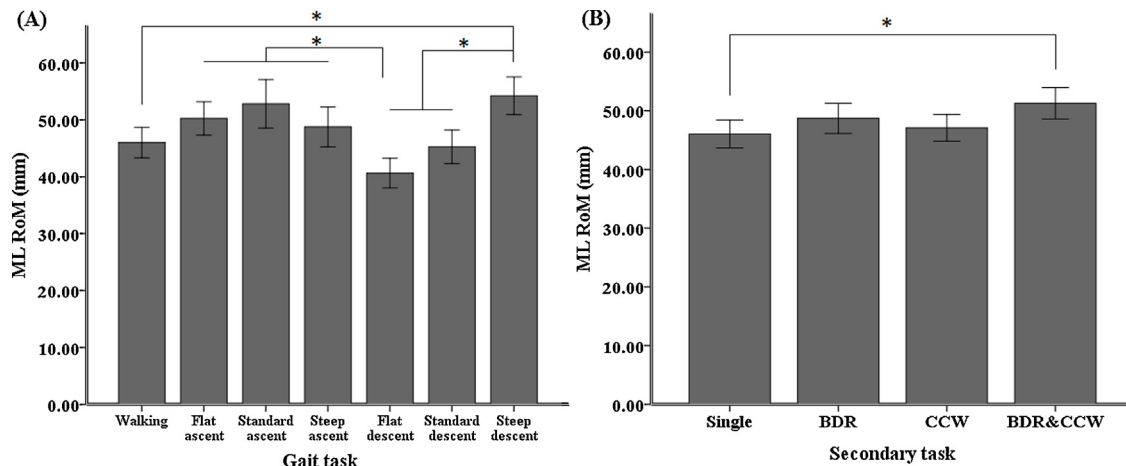


Fig. 3. ML-RoM shown as a function of (A) gait task (level walking, flat, standard and steep stair ascent and descent), (B) secondary task (single task, BDR, CCW and BDR&CCW). BDR, backward digit recall; CCW, carrying cup of water. Significant differences ($p < 0.05$) between the conditions are indicated by *. Error bars indicate standard error.

4.06 to 5.42 cm). Other studies reported an increased risk for falls only for larger displacements of ML COM (>6 cm) among community-dwelling older adults [24].

Gait speed decreased with stair steepness, which is also reported by others [16]. ML-RoM only showed an increase during descent. Consistent with other studies, our results show that stair ascent was more challenging than stair descent and level walking [22], which is shown by slower gait speed and higher ML-RoM. A possible explanation is that during ascent, system resources are directed towards *concentric* muscular action and energy generation, whereas during descent, resources are only directed towards *eccentric* muscle contraction, which is less demanding.

ML-RoM was not significantly affected when ascending steeper stairs—this may represent a successful effort to avoid imbalance. These observations are similar to those made during level walking and whilst stepping over an obstacle [24,25]: the average ML-RoM across all obstacle height conditions was significantly greater than during unobstructed walking but showed no significant increase as obstacle height increased. In our study, the largest ML-RoM may be indicative of cautious behaviour to reduce the risk of falling. Specifically, more caution is taken when stepping on a steeper stair.

In the current study, the type and complexity of the secondary task altered gait performance and ML-RoM. Performing a secondary task significantly decreased the gait speed indicating an interference of attentional demands between the secondary and the gait task. Previous studies have reported a similar alteration; motor and cognitive cost of dual-task walking heavily depends on the type and perceived complexity of the cognitive task being performed [9,12].

In each gait task, performing a cognitive task resulted in a slightly reduced gait speed indicating an attentionally demanding secondary task. In the cognitive task, the attentional resources were split and allocated arbitrarily to each task; the additional cognitive task draws attentional resources away from gait [5], thereby decreasing the gait speed and increasing ML-RoM compared to single task in this study. However, the increased ML-RoM in this study may also be due to an effort to produce a compensatory movement aimed at maintaining sideways stability which is consistent with previous research [24].

When the manual task was performed, gait speed reduction was more apparent compared to the cognitive task. A manual task shares the same resources as postural control. Thus, performing a manual task had more effect on gait performance. In contrast to these findings, another study reported that participants walked

slower while performing a cognitive task as opposed to a manual task [12]. A possible explanation could be the fact that this study used cognitively impaired older people as opposed to younger adults.

The manual task exhibited a potential in increased dynamic stability in ML direction compared to the cognitive task, however, the effect was not significant in this study. In the present work, during the manual task, subjects were required to consciously pay attention to postural control in order to hold the cup straight. Further study of different types of manual tasks may support the idea that the constraint imposed by a more demanding manual component of the dual-task interplayed with the postural component, leading to improved body stability [13,14]. Also the cross-talk theory supports our findings, suggesting that performing two tasks which share the same resources may cause less interference in the performance of either tasks [30].

Conceptually and experimentally, BDR&CCW is the most difficult task and resulted in the most conservative gait in all gait tasks in this study. Attentional resources are limited in capacity; Result for dynamic stability and gait speed during BDR&CCW in all gait tasks demonstrated higher attentional demands of the secondary task and overlapping processing resources.

A limitation in the current study is that our results only show the effects of one particular type of manual task during gait. Investigating the kinetics of lower-extremities may provide a deeper understanding of the stair gait mechanisms under the secondary task condition. Also, a further application to the elderly population or patients with balance problems may enhance our understanding of the mechanisms underlying the increase of falls in the elderly. Finally, findings of this study, in particular the strategy chosen to avoid falls in challenging circumstances, can be used to evaluate balance and gait, and predict future falls.

5. Conclusion

Compromised ML-RoM and decreased gait speed are a compensation to improve dynamic stability and optimize the secondary task performance. The subjects in this study generally walked more slowly with alteration in ML-RoM when they were asked to walk and concurrently perform another task. The degree of reduction of gait speed and variation in ML-RoM changed by increasing gait and secondary task complexity. However, mean speeds and ML-RoM in all cases remained within normal limits. Variation in ML-RoM within the normal range does not necessarily indicate an increased risk of falling. This study suggests that the

unconscious alteration in gait speed and COM RoM might be key to avoiding hazards and preventing falls and reflects an increase in dynamic gait stability.

Acknowledgments

This work is supported by the Dutch research project COMMIT—Virtual Worlds for Well-Being. The authors would like to thank Nicolas Pronost for his involvement in setting up the experiment, Ali A. Sangari for his help with analysing the results, and Yasaman Ganji and Mohammed N. Ashtiani for proofreading the manuscript.

Conflict of interest

There are no conflicts of interest.

References

- [1] Stel VS, Smit JH, Pluijm SM, Lips P. Consequences of falling in older men and women and risk factors for health service use and functional decline. *Age Ageing* 2004;33:58–65.
- [2] Startzell JK, Owens DA, Mulfinger LM, Cavanagh PR. Stair negotiation in older people: a review. *J Am Geriatr Soc* 2000;48:567–80.
- [3] Ojha HA, Kern RW, Lin C-HJ, Winstein CJ. Age affects the attentional demands of stair ambulation: evidence from a dual-task approach. *Phys Ther* 2009;89:1080–8.
- [4] Vallabhajosula S, Tan CW, Mukherjee M, Davidson AJ, Stergiou N. Biomechanical analyses of stair-climbing while dual-tasking. *J Biomech* 2015;48:921–9.
- [5] Asai T, Misu S, Doi T, Yamada M, Ando H. Effects of dual-tasking on control of trunk movement during gait: respective effect of manual-and cognitive-task. *Gait Posture* 2014;39:54–9.
- [6] Woollacott M, Shumway-Cook A. Attention and the control of posture and gait: a review of an emerging area of research. *Gait Posture* 2002;16:1–14.
- [7] Yogev-Seligmann G, Hausdorff JM, Giladi N. The role of executive function and attention in gait. *Movement Disord* 2008;23:329–42.
- [8] Kelly VE, Janke AA, Shumway-Cook A. Effects of instructed focus and task difficulty on concurrent walking and cognitive task performance in healthy young adults. *Exp Brain Res* 2010;207:65–73.
- [9] Patel P, Lamar M, Bhatt T. Effect of type of cognitive task and walking speed on cognitive-motor interference during dual-task walking. *Neuroscience* 2014;260:140–8.
- [10] Schaefer S, Jagenow D, Verrel J, Lindenberger U. The influence of cognitive load and walking speed on gait regularity in children and young adults. *Gait Posture* 2015;41:258–62.
- [11] Simoni D, Rubbieri G, Baccini M, Rinaldi L, Becheri D, Forconi T, et al. Different motor tasks impact differently on cognitive performance of older persons during dual task tests. *Clin Biomech* 2013;28:692–6.
- [12] Taylor ME, Delbaere K, Mikolaizak AS, Lord SR, Close JC. Gait parameter risk factors for falls under simple and dual task conditions in cognitively impaired older people. *Gait Posture* 2013;37:126–30.
- [13] Morioka S, Hiyamizu M, Yagi F. The effects of an attentional demand tasks on standing posture control. *J Physiol Anthropol Appl Hum Sci* 2005;24:215–9.
- [14] de Lima AC, de Azevedo Neto RM, Teixeira LA. On the functional integration between postural and supra-postural tasks on the basis of contextual cues and task constraint. *Gait Posture* 2010;32:615–8.
- [15] Riener R, Rabuffetti M, Frigo C. Stair ascent and descent at different inclinations. *Gait Posture* 2002;15:32–44.
- [16] Stacoff A, Diezi C, Luder G, Stüssi E, Kramers-de-Quervain IA. Ground reaction forces on stairs: effects of stair inclination and age. *Gait Posture* 2005;21:24–38.
- [17] Vallabhajosula S, Yentes JM, Momcilovic M, Blanke DJ, Stergiou N. Do lower-extremity joint dynamics change when stair negotiation is initiated with a self-selected comfortable gait speed? *Gait Posture* 2012;35:203–8.
- [18] Vallabhajosula S, Yentes JM, Stergiou N. Frontal joint dynamics when initiating stair ascent from a walk versus a stand. *J Biomech* 2012;45:609–13.
- [19] Maylor EA, Wing AM. Age differences in postural stability are increased by additional cognitive demands. *J Gerontol Ser B: Psychol Sci Soc Sci* 1996;51:P54–143.
- [20] Kadaba MP, Ramakrishnan H, Wootten M. Measurement of lower extremity kinematics during level walking. *J Orthopaed Res* 1990;8:383–92.
- [21] Zeni Jr J, Richards J, Higginson J. Two simple methods for determining gait events during treadmill and overground walking using kinematic data. *Gait Posture* 2008;27:710–4.
- [22] Protopapadaki A, Drechsler WI, Cramp MC, Coutts FJ, Scott OM. Hip, knee, ankle kinematics and kinetics during stair ascent and descent in healthy young individuals. *Clin Biomech* 2007;22:203–10.
- [23] Grenholm A, Stensdotter A-K, Häger-Ross C. Kinematic analyses during stair descent in young women with patellofemoral pain. *Clin Biomech* 2009;24:88–94.
- [24] Chou L-S, Kaufman KR, Hahn ME, Brey RH. Medio-lateral motion of the center of mass during obstacle crossing distinguishes elderly individuals with imbalance. *Gait Posture* 2003;18:125–33.
- [25] Chou L-S, Kaufman KR, Brey RH, Draganich LF. Motion of the whole body's center of mass when stepping over obstacles of different heights. *Gait Posture* 2001;13:17–26.
- [26] Mian OS, Narici MV, Minetti AE, Baltzopoulos V. Centre of mass motion during stair negotiation in young and older men. *Gait Posture* 2007;26:463–9.
- [27] Catena RD, van Donkelaar P, Chou L-S. Cognitive task effects on gait stability following concussion. *Exp Brain Res* 2007;176:23–31.
- [28] Shumway-Cook A, Woollacott M. Attentional demands and postural control: the effect of sensory context. *J Gerontol-Biol Sci Med Sci* 2000;55:M10.
- [29] Silsupadol P, Siu K-C, Shumway-Cook A, Woollacott MH. Training of balance under single-and dual-task conditions in older adults with balance impairment. *Phys Ther* 2006;86:269–81.
- [30] Schmidt RA, Lee T. *Motor Control Learning: Human Kinetics* 1988.