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GAIPOS-4265; No. of Pages 3
ARTICLE IN PRESS
Gait & Posture xxx (2014) xxx–xxx
Contents lists available at ScienceDirect
Gait & Posture
journal homepage: www.elsevier.com/locate/gaitpost

Short Communication

Towards the importance of minimum toe clearance in level ground walking in a healthy elderly population

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ARTICLE INFO

Article history:
Received 28 January 2014
Received in revised form 14 July 2014
Accepted 21 July 2014

Keywords:
Minimum toe clearance
Dual-task costs
Gait variability

ABSTRACT

Tripping is presumed to be the principal cause for falls during walking. At minimum toe clearance, the potential for trip-related falls is considered to be highest. Thus, controlling minimum toe clearance is essential for walking without tripping. In theory, the central nervous system should therefore give priority to accurate control of the variability in minimum toe clearance, as compared to other gait parameters, since people tend to only modify variability in any given task if it interferes with the task performance. The aim of this study was to determine whether elderly individuals show less increase in variability of minimum toe clearance during a dual-task condition (where an increase of gait variability is provoked), while allowing a larger range of variability in the other gait parameters. Forty elderly participants walked back and forth on a 25 m long track for five minutes. They then walked a second time performing an additional cognitive task. The variability in stride time, stride length and minimum toe clearance as well as dual-task costs of each gait parameter were calculated for each walk. The variability in minimum toe clearance did not change during dual task-walking, whereas the variability of stride length and stride time increased, showing dual-task costs of about 66% and 84%, respectively. To avoid additional detrimental load on the central nervous system, the modification of task-irrelevant variability may be tolerated during dual-task conditions, whereas minimum toe clearance is controlled with high priority.

1. Introduction

Falls in the elderly population represent a major cost to the public health system [1,2]. Tripping while walking is presumed to be the principal cause of falls [3], and at minimum toe clearance (MTC), the potential for a trip-related fall is considered to be highest [4]. Extreme levels of variability in human walking have been reported to be a predictor of risk of falling [5] and constitute a key neuromuscular deficit in elderly people [6]. However, according to the minimum intervention principle, humans tend to only modify this variability if it interferes with task performance [7], since the additional control of task-irrelevant variability would constitute additional detrimental load on the central nervous system [8]. Controlling the swing phases of gait, and consequently MTC, is considered a precise-end-point control task [4,9]. From a falls perspective, controlling MTC in level-ground walking could be the task-relevant variable, whereas the control of other gait parameters may be less important for goal-directed task performance (e.g. walking without tripping). If this is true, an efficient central nervous system should give high priority to accurate control of MTC as compared to other gait parameters. In plain terms, the central nervous system may allow a greater degree of variability in the less important (task-irrelevant) variables, while minimising variability in task-relevant parameters of human walking [8]. If that assumption is true, dual-task costs (defined as a percentage increase in gait variability) would be lower in MTC variability than in the other spatial or temporal gait parameters' variability to prevent trips. The aim of the current study was to explore whether the central nervous system of healthy elderly individuals minimises variability in MTC when an increase of gait variability is experimentally provoked (with a cognitive dual task) while allowing an increase in variability in other spatial or temporal gait parameters. We hypothesised that in healthy elderly individuals, the variability in MTC would increase much less than that of other gait parameters when a dual task is introduced, as compared to normal level walking.

2. Methods

From a larger study (study protocol of the local ethics committee: 22|12), we recruited 40 elderly (age: 67.6 ± 3.4 years)

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http://dx.doi.org/10.1016/j.gaitpost.2014.07.016
0966-6362/

Table 1
Mean gait measures for normal walking and dual-task walking. Note that descriptive statistics for the measures are presented in median (interquartile range) and dual task-costs are presented with mean (standard deviation).

	Mean (SD) of walking speed	Mean (SD) of stride time	Mean (SD) of stride length	Mean (SD) of minimum toe clearance
Normal walking	1.4409 (0.1313) m/s	1.0234 (0.0652) s	1.4704 (0.1219) m	0.0224 (0.0089) m
Dual-task walking	1.2785 (0.1449) m/s	1.1114 (0.1025) s	1.4012 (0.1223) m	0.01999 (0.0080) m
z value	−5.475	−5.371	−5.229	−4.451
p value	.000	.000	.000	.000

Table 2
The variability of gait measures for normal walking and dual-task walking. Note that descriptive statistics for the measures are presented in median (interquartile range) and dual task-costs are presented with mean (standard deviation).

	SD of stride time	SD of stride length	SD of minimum toe clearance
Normal walking	0.0183 (0.0063) s	0.0289 (0.0092) m	0.0053 (0.0015) m
Dual-task walking	0.0350 (0.0342) s	0.0467 (0.0267) m	0.0048 (0.0019) m
z value	−3.407	−4.566	−1.739
p value	.000	.000	.090
Dual-task costs	84.2 (115.5)%	65.9 (85.6)%	−7.1 (26.8)%

participants who were not suffering from orthopaedic or neurological complaints (mini-mental state examination performance above 28 points). After they signed written informed consent, the subjects were asked to walk back and forth along a 25 m track at their preferred walking speed for five minutes. Thereafter, participants were allowed five minutes rest. After the break, subjects walked again for about the same time while loudly reciting serial three subtractions starting from the number 600. It has been reported that the walking performance of older people significantly decreases while reciting serial three subtractions [10]. As the control of temporal and spatial gait parameters may be governed separately by the motor cortex [11], we examined both temporal and spatial gait parameters. Thus, the variability (standard deviations) of stride length and stride time, which are related to gait control mechanisms, and should be considered as markers of adaptability in walking [12], and MTC were calculated using data derived from inertial sensors (MTw, Xsens Technologies B.V., Enschede, The Netherlands) attached to the arch of the subjects' feet. Data from the first 30 s of walking was omitted and data from the first and last 2.5 m before and after changing direction was removed to insure steady state walking. Exactly 200 strides, considered sufficient to estimate gait variability, were used for the data processing [13]. This procedure has been evaluated and found to be reliable ($ICC_{2,1}$ = 0.812) in Ref. [14].

As not all outcome measures were normally distributed, group differences between normal walking and dual-task walking were compared using the Wilcoxon-test using IBM SPSS Statistics 20. The level of significance was set to α = .05. Dual-task costs were calculated as the percentage change in gait variability measures from single task walking to dual-task walking as described in Ref. [15].

3. Results

Our data show that the walking speeds and mean gait parameters (Table 1) differed between the trials (p = .000) and that the variability of stride length and stride time (Table 2) in cognitive dual-task walking was significantly higher as compared to normal walking (p-value for each test = .000). The dual-task costs for the variability of stride length, and stride time were 65.9% and 84.2%, respectively. However, the variability of MTC did not change (p = .090) and the dual-task cost was −7.1%. Note that here the percentage change is negative, therefore, interpreting a possible trend (.050 < p < .100) would not be valid.

4. Discussion

This is the first study to explore the origins of changes of variability in task-relevant and task-irrelevant gait parameters from normal walking to cognitive dual-task walking. We believe that older adults adopt a preferential lower increase in MTC variability even during a dual-task paradigm. At MTC, the potential for a trip-related fall is considered to be highest [4] and should be controlled with the highest priority in all situations. Hence, we expected a smaller increase in the variability of MTC (task-relevant variable) than in other temporal and spatial gait parameters. Surprisingly, our data showed that relative to normal walking, variability of MTC in dual-task walking did not significantly change, whereas stride length and stride time increased in variability by more than two thirds. In all three gait variability parameters, different walking speeds across trials could represent a potential confounder. However, as MTC variability is also highly reproducible in healthy elderly individuals [14], we suggest that a normally functioning central nervous system will give high priority to control of the task-relevant variable (MTC). Perhaps, elderly individuals at high risk of tripping are not able to control MTC even in critical situations. If so, MTC variability might be an effective diagnostic tool for identifying future fallers. The investigation of the control of MTC in individuals at risk of falling in single walking and dual-task walking is, therefore, highly recommended.

Acknowledgement

No external sources of support have to be declared.

Conflict of interest

There is no conflict of interests.

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Please cite this article in press as: Hamacher D, et al. Towards the importance of minimum toe clearance in level ground walking in a healthy elderly population. Gait Posture (2014), http://dx.doi.org/10.1016/j.gaitpost.2014.07.016