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

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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.

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

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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