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Response inhibition during avoidance of virtual obstacles while walking

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Abstract While walking, one often has to suppress and adjust a planned step in order to avoid a fall. Given that steps are preprogrammed this requires some form of motor inhibition. Motor inhibition is commonly tested in hand function and only recently attempts have been made to evaluate inhibition in the lower limbs, during step initiation. As adequate motor inhibition might play a role in avoiding falls a test to assess response inhibition during walking would be valuable. We developed a task in which subjects walked on a treadmill by stepping on projected patches of light, which could suddenly change color forcing the subjects to avoid it by shortening or lengthening their steps. The difficulty level was manipulated in 4 conditions by changing the distance available to respond. We hypothesized that larger demands on motor inhibition during walking would produce more failures and tested the performance of young adults ($n = 12$) in order to establish the protocol for use in older adults. The failure rate on the walking test was analyzed. Reducing the available response distance by 150 mm from the easiest condition resulted in a significant increase in failure rates from 15.6% to 65.1%. Therefore, results indicate this novel test can be used to assess the level of motor inhibition during walking. Additionally, in comparison to previous literature on obstacle avoidance, our experiment shows that changing a precise aiming movement is considerably more challenging than changing the same movement executed automatically.

Keywords

Response inhibition; Obstacle avoidance; Precision stepping; Gait; Accidental falls

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1 Introduction

During walking humans plan swing limb trajectories in advance [1]. In case of a perturbation, one needs to inhibit the preplanned step and find an alternative foot landing position to avoid instability and falling.

Response inhibition in the lower limbs has been assessed during quiet standing [2] and step initia-

tion [3-5], showing that impaired ability to modify voluntary step initiation contributes to the risk of falling [4,5] and that motor inhibition is required for a timely onset of a voluntary stepping reaction [3]. However, these experiments focused mainly on movement preparation [3,5] while most falls occur during walking [6], which is a continuous activity more demanding than step initiation.

Therefore, in the present pilot study we devel-

oped a task to measure the ability to modify an ongoing movement during walking using an obstacle avoidance (OA) task. Similar to the work of Chen et al. [7-9], we used virtual obstacles projected on a treadmill. However, in our case the subjects aimed to step on virtual stepping stones. These stones could suddenly change to obstacles, thus stressing the need to inhibit an ongoing step. Hence our unperturbed steps were precision steps, while the perturbed steps required these precise aiming steps to be suppressed and adjusted.

We hypothesized that larger demands on motor inhibition during walking would produce more failures and tested the performance of young adults in order to establish the protocol for further use in older adults.

2 Methods

The experiment was approved by the local ethical committee according to the declaration of Helsinki and twelve young adults (22.58 ± 2.5 years, 5 women) without musculoskeletal problems or vision impairments participated after signing informed consent forms.

Subjects walked on the C-Mill treadmill (ForceLink, Culemburg, The Netherlands) at a speed of 3 km/h by stepping on patches of light that served as stepping stones. If a stone suddenly changed color it was to be considered an obstacle and subjects were instructed to avoid it by either shortening or lengthening their step. Color changing stones were randomly distributed and their position was defined by the available response distance (ARD), the distance between subject’s center of pressure and a virtual line in front of the subjects (Fig. 1). Task difficulty was increased by decreasing the ARD. Depending on individual step length, the phase of the step cycle could differ for any given ARD. The largest between subject difference in average step length was 8 cm meaning that, given the speed of 3 km/h and a step cycle of 1 s, there could be a change of about 10% of the step cycle for any given ARD condition (Table 1 shows data on step lengths).

Following gradual introduction to the task, the starting level difficulty was determined by performing short versions of the task (three obstacles per level) starting at a very easy ARD (600 mm) and increasing difficulty until the first failure. This was repeated and the mean ARD at which the two failures occurred served as individual starting level.

Table 1: Average step lengths and individually determined “easy” level ARD values per subject. Step lengths were calculated from recorded reflective marker data as half of the distance between two consecutive left heel strikes and averaged for each subject.

Subject	Step length (m)	“Easy” ARD (mm)
1	0.54	450
2	0.53	600
3	0.54	450
4	0.52	500
5	0.53	500
6	0.58	550
7	0.50	450
8	0.53	500
9	0.54	550
10	0.54	600
11	0.53	550
12	0.53	550
AVERAGE	0.53	520.8
SD	0.02	51.9
MIN	0.50	450
MAX	0.58	600

The protocol consisted of a baseline condition (walking without obstacles) followed by 4 conditions with increasing difficulty. The individually determined starting level was used for the easiest condition and for the subsequent conditions the ARD was decreased each time by 50 mm. Each condition consisted of 20 obstacles that could appear on both sides of the treadmill, at a frequency of 7 per minute.

Failure rates were calculated from video recordings of the experiment by dividing the number of failures by the total number of obstacles presented. Following a ShapiroWilk normality check the data were analyzed with a GLM repeated measures ANOVA and Tukey HSD post hoc tests using Statistica 11 (StatSoft, Tulsa, OK, USA). Level of statistical significance was set at $\alpha = 0.05$.

3 Results

Results are shown in Fig. 2. Subjects had a gradient in performance matching the increasing difficulty, although individuals differed in their ability to perform at a given ARD. Repeated measures ANOVA revealed main effects of difficulty

Figure 1: Experimental setup and conditions. Subjects walked on the C-Mill (ForceLink, Culemburg, The Netherlands), a system comprising a projector and an instrumented treadmill with stepping stones projected relative to subjects' gait (a). This system can detect foot contacts, predict subsequent steps, and, based on this, project gray patches of light (serving as stepping stones) onto the treadmill. Distance between the stepping stones (i.e. step length) was individually adjusted to be comfortable and was held constant during the experiment. The subjects were instructed to walk and step on the stones (b), unless a stone changed color from gray to purple (c). In the latter case the purple stepping stone was to be considered an obstacle and subjects were instructed to avoid it by either shortening or lengthening their step (d). Stepping to the side of the obstacle or on it was considered a failure. The change in color could appear in front of any foot, at a frequency of 7 per minute. The timing of color changes was randomly distributed and the position of the stone to color was defined by the available response distance (ARD). ARD is the distance between subject's center of pressure and a virtual line in front of the subjects (c). The first stepping stone ahead of this line changed color. Hence the stepping stone that was about to change color could be situated just behind this virtual line or at an additional distance, corresponding to the distance between the virtual line and the position of the stepping stones. Maximum possible distance was therefore 'ARD + step length' and dependent on individual's step length, while the minimal distance was defined by ARD.

($F = 80.57$, $p < 0.001$). Increasing difficulty significantly increased failure rates for all conditions (Tukey HSD, all $p < 0.001$).

4 Discussion

We presented a novel test for assessing response inhibition during walking, in which subjects needed to unexpectedly modify precision aiming steps. Healthy young adults showed consistent increases in failure rates at their individually tailored difficulty levels, proving that the test is sensitive to measure response inhibition as function of task difficulty.

Our test is novel in that previous tests have focused on gait initiation rather than on ongoing gait [3-5]. Nevertheless, there are similarities. During step initiation about 5 times more failures were found for a 200 ms available response time (ART) decrement [4] while we found about 4 times more errors (15.6% and 65.1%) for a 150 mm ARD decrement (equivalent to 180 ms ART at a speed of 3 km/h).

Similarly, it is of interest to compare the present work on precision stepping with studies on avoidance of physical [10,11] and virtual [7,8] obstacles. These studies used ART, defined as the time between obstacle release and the predicted moment of the contact with the obstacle if there would be no avoidance reaction. They found success rates approaching 100% at ARTs around 350-450 ms for both overground [7,8] and treadmill walking [10,11]. In contrast, our subjects did not reach a 100% success rate with ARDs of 600 mm (an equivalent of 720 ms ART). This may be explained by differences in the methodology and task complexity. Our subjects aimed to step on the stone before it turned into an obstacle and had to suppress and adjust this precise aiming movement, which was not the case in the previous OA studies. Additionally, our obstacles could randomly appear on both sides, while previously they would either be projected across the whole walkway [7,8] or only on one side of the treadmill [10,11]. If the same obstacles could appear at either side on a treadmill a significant response latency increase was reported [12]. These differences underline the fact that the present task is more challenging than previous OA tasks. Apparently, it takes substantial time to change an ongoing motor plan for a precise aiming step and this ability deteriorates when the time to respond decreases.

In the present experiments, increasing difficulty levels were used sequentially rather than randomly. This sequence was chosen because starting with trials in which they failed very frequently was very demotivating for the subjects during pilot experiments. In principle, this sequential order could have resulted in fatigue effects. To verify this point we repeated the “easy” condition at the end of the series in one subject. If fatigue played a role one would expect the failure rate to be higher in the repeated “easy” condition but the failure rate did not differ (15% in both cases). The sequence could in principle also have induced learning effects. However, this would have led to improvements in performance over time and clearly this was not the case.

It is concluded that the present task is appropriate for testing response inhibition during precision stepping and can safely be used to assess changes in response inhibition in elderly.

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Conflict of interest

Authors have no conflict of interest.

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Figure 2: Average group results ($n = 12$) and individual failure rates per condition (a) and available response distance (b). Condition 1 is the easiest and the difficulty is increasing in subsequent conditions. Decreasing the available response distance increased the difficulty of the task. Error bars denote standard deviations. * indicates statistical significance of the task ($p < 0.05$).

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