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Attentional demands of cued walking in healthy young and elderly adults

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ABSTRACT

Acoustic and visual cues are frequently used in gait rehabilitation. Attuning the steps to the cues is attentionally demanding. We examined the attentional demands of walking to two types of cues using a probe reaction time (RT) task. The steps were cued by either metronome beeps or visual stepping stones projected on a treadmill. The coupling between gait and these cues was assessed using a perturbation paradigm. In view of age-related changes in attentional demands of motor control, both elderly and young adults were tested. RTs were determined for walking to the two types of cues, as well as for three control conditions, viz. uncued walking, standing, and sitting. For all conditions, RTs were higher for elderly adults. However, the difference between elderly and young adults did not vary over conditions. Uncued walking required more attention than did standing and sitting. The attentional demands were further elevated during cued walking, with larger RTs for walking to visual stepping stones than to metronome beeps. Because the coupling to the cues was superior in the stepping stones condition, this type of cues seems to aid cued walking by allocating higher levels of attention to task-relevant information (viz. future footfall positions). Hence, the observed differences between the two cueing types may be associated with the natural dependence of gait on visual information.

1. Introduction

Vision plays an essential role in the control of human locomotion, both at a local and a global level [1]. We use visual targets [2] and optic flow [3] to navigate through our environment and need information about local features of the terrain to secure adequate foot placement [4]. Processing this gait-specific visual information is attentionally demanding, which becomes particularly apparent when walking is combined with a secondary task that also draws on visual resources [5]. This natural dependence of gait on visual information is exploited when visual cues (e.g., markers on the floor) are presented to improve pathological gait [6–10].

Recently, we compared performance of healthy elderly adults when walking to acoustic cues (metronome beeps) or visual stepping stones [11]. By projecting the stepping stones on a treadmill, comparable conditions for the two cueing types were created in terms of walking velocity, step frequency, and step length. Visual stepping stones resulted in a tighter coupling between gait and the cues than did metronome beeps, as evidenced by a swifter response to perturbations in the cueing sequence. Hence, notwithstanding the beneficial effects that have been reported for acoustically cued walking in various patient groups [10,12–18], the use of visual stepping stones may be preferable for evaluating or training one's ability to make step adjustments [11].

Although walking to cues has beneficial effects, it comes at a cost: walking to both acoustic cues [19] and visual targets [9] have been demonstrated to be attentionally more demanding than uncued walking. To shed more light on the relation between cued walking and attentional load, the present study compared the attentional demands of walking to visual stepping stones to those of walking to acoustic cues, as well as three reference conditions (uncued walking, standing, sitting). Insight in this regard is of practical relevance, in view of altered task-specific attentional demands in particular patient populations (e.g., hemi-neglect or Parkinson's disease) and age-related changes in the attentional load of various motor tasks, including postural balance and walking [5,20–22]. For this reason, performance of young adults was compared to that of healthy elderly persons. To examine attentional load a secondary probe reaction time (RT) task was used. In view of a fair comparison between the two cueing conditions, this task did not involve any visual or acoustic component. To determine whether potential differences in attentional demands over the two cueing conditions were related to the degree of coupling between gait and cues, the swiftness of gait adjustment responses to perturbations in the cueing sequences was also assessed for both age groups.

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2. Methods

Twelve elderly adults (5 women, 7 men; mean age: 60.5 yrs, range: 55–69 yrs) and twelve young adults (4 women, 8 men; mean age: 24.9 yrs, range: 22–28 yrs) participated. None reported limited mobility, uncorrected visual or acoustic impairment, or cardiovascular or cardiopulmonary problems. The experiment was approved by the local Ethics Committee.

2.1. Apparatus

An instrumented treadmill with a large force platform embedded (ForceLink, Culemborg, The Netherlands) allowed for online detection of gait events (e.g., heel strike) and gait characteristics (e.g., cadence, step length) [23] and for presentation of visual and acoustic cues in a movement-dependent manner [24] (see also [11,25]).

In the visual cueing (VC) condition, rectangular stepping stones (length: participant's shoe length; width: 30 cm) were presented alternately to the left and right foot and approached the participant at the speed of the treadmill belt. The front of the treadmill was elongated by 1.80 m, so that 4–5 stepping stones were projected at each moment in time (Fig. 1; [11]).

In the acoustic cueing (AC) condition, computer-generated beeps cued the left (440 Hz) and right (1000 Hz) heel strikes. They were presented through hearing protection earphones (Bilsom 787 flex II or Peltor HRXS7A-01), which muted any external sounds. These earphones were worn throughout the experiment to help the participants concentrate.

The probe RT task involved computer-generated vibrating stimuli (custom-built vibrator; duration: 300 ms) on the nondominant wrist. The response button was held in the dominant hand (sampling rate: 1000 Hz).

2.2. Preparation

After walking on the treadmill for at least 5 min (at various velocities), participants practiced walking to acoustic ('step to the beat') and visual cues ('step on the stepping stones'), presented at the individual's preferred cadence (as determined for 10 s of uncued walking). Subsequently, the most comfortable uncued treadmill walking speed (CWS) of the participant was determined, which was used during all walking trials.

2.3. Procedure

2.3.1. Perturbation trials: coupling between gait and cues

After determining the participant's cadence and step length (10 s, uncued treadmill walking), cues (AC or VC) corresponding to these gait characteristics were presented during the next 25 s. The participants were instructed to synchronize the steps to these cues. At a random moment after 8–12 s of cued walking, a sudden phase shift of +60° (phase delay) or −60° (phase advance) of all subsequent cues was applied (see [11] for full details). For AC walking, this entailed a temporal shift of ±1/6th of the interval between consecutive ipsilateral beeps. For VC walking, the stepping stones were either arrested at heel strike and subsequently released after 1/6th of the stride time interval (+60°), or they were suddenly displaced towards the participant over a distance of 1/6th stride length at 1/6th of the stride time interval before heel strike (−60°). Thus, the perturbations in AC and VC conditions were compatible regarding timing, size, and unpredictability [11]. Gait adjustments were required to restore synchronization with the cues: longer-step responses (larger step time and length) and shorter-step responses (smaller step time and length) for a +60° and −60° phase shifts, respectively.

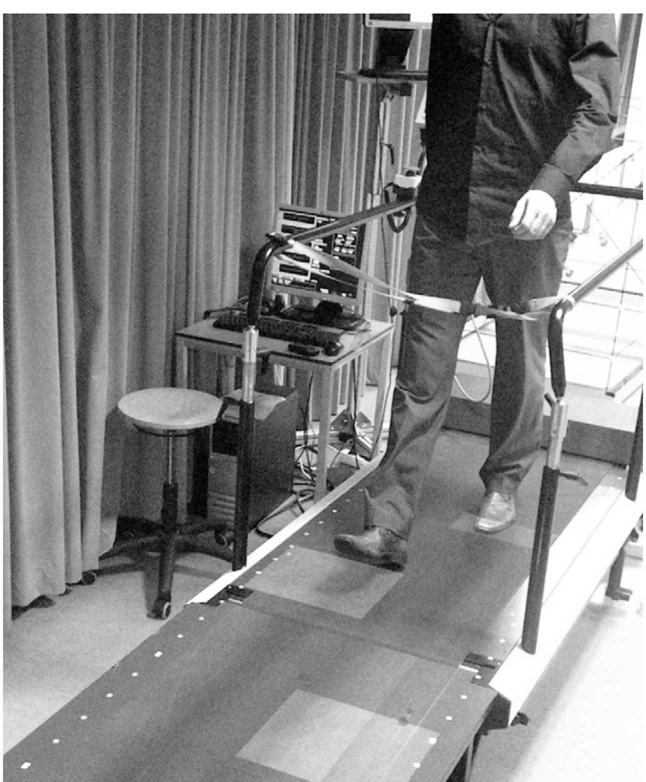

Fig. 1. Overview of the experimental setup (i.e., stepping stones condition).

Eight perturbation conditions were tested: 2 (cueing type: AC vs. VC) × 2 (perturbation direction: +60° vs. −60°) × 2 (perturbed foot: left vs. right). First all trials for one cueing type (AC or VC; counterbalanced) along with one dummy trial (i.e., without perturbation; not included in analysis) were presented (random order), followed by the nine trials for the other cueing type (including one dummy trial). Each participant performed two of these blocks,[1] separated by a short break if desired.

2.3.2. RT trials: attentional demands

The attentional demands of walking to either type of cues as well as three control conditions (sitting, standing, and uncued treadmill walking, cf. [22]) were examined. During each trial, 10 vibrating stimuli were presented, at random moments separated by 3–6 s. Participants had to press the button as soon as they felt the vibration, as practiced prior to the experiment.

The sitting condition entailed sitting on a chair without armrests, with the feet supported. The standing condition involved standing upright with the feet at hip width. The first stimulus was presented after at least 6 s of comfortable sitting or standing (trial duration: 1 min). For the three walking conditions, stimuli were presented at the moment of heel strike of either foot (5 left, 5 right), in random order (trial duration: 2.5 min). The first stimulus was presented after about 75 s. Participants were instructed to follow the cues (if present) as accurately as possible, and were informed that RT stimuli would be presented in the second half of the trial.

Two sets of five trials (i.e., one trial for each condition, each comprising 10 stimuli) were presented in counterbalanced order, separated by a short break if desired. Hence, 20 RTs were recorded for each condition.

2.4. Data analysis

2.4.1. Perturbation trials

The analysis was identical to that of [11]. For each step, relative phase ϕ (in°) between gait and cues was calculated. For AC conditions $\phi = 360° \cdot (t_{\text{cue}} - t_{\text{HS}})/T_{\text{cue}}$, with t_{cue} representing the instant of acoustic pacing, t_{HS} the instant of the corresponding heel strike, and T_{cue} the time interval between consecutive ipsilateral cues. For VC conditions time instants t were replaced by anterior–posterior positions y, yielding $\phi = 360° \cdot (y_{cue} - y_{foot})/Y_{cue}$, with y_{cue} representing the center of the stepping stone, y_{foot} the center of the foot, and Y_{cue} the center-to-center distance between two consecutive ipsilateral stepping stones.

Pre-perturbation mean relative phase ($\bar{\phi}_{pre}$) and standard deviation ($SD_{\phi,pre}$) were determined for the five consecutive strides immediately preceding the perturbation. Post-perturbation $\bar{\phi}_{post}$ and $SD_{\phi,post}$ were determined for the post-perturbation window of five consecutive strides with the lowest cumulative phase error (cf. [11]). Trials were excluded from analysis if gait was not coupled to the cues, or if no stable post-perturbation phase relation was achieved (for quantitative criteria, see [11]); 12% of the AC trials (elderly: 9%; young: 14%) and 1% of the VC trials (elderly: 0.5%; young: 1.5%) were excluded. For each included trial, the number of steps required to return to the pre-perturbation level of coupling (N_{return}) was equated with the middle step of the first post-perturbation window of three steps for which $\bar{\phi}$ fell within the reference range $\bar{\phi}_{post} \pm 1.96 \cdot SD_{\phi,pre}$ and stayed within this range for at least six consecutive windows [11].

2.4.2. RT trials

RT was defined as the time interval between the onset of the vibrating stimulus and the start of the corresponding response. For each task, mean RT was calculated (on average 0.34 incorrect responses were excluded per participant per condition).

To examine potential task-prioritization effects of the RT task on gait parameters during the three walking conditions, step width and step length (mean [M] and standard deviation [SD]; see [26]) were determined for the first part (i.e., the last 45 s before the first RT stimulus was presented) and the second part (i.e., the first 45 s of walking while the RT stimuli were presented) of each trial. For the cued walking conditions, mean relative phase ($\bar{\phi}$; see above) between cues and heel strikes was also determined for these parts of the trial, as well as its variability (SD_{ϕ}).

[1] Due to measurement errors, the first set of 9 AC trials of one elderly participant could not be analyzed.