Gait & Posture 42 (2015) 534–538

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Tactile pavement for guiding walking direction: An assessment of heading direction and gait stability

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ARTICLE INFO

Article history:
Received 25 March 2015
Received in revised form 17 August 2015
Accepted 21 August 2015

Keywords:
Gait stability
Heading direction
Tactile pavement
Reduced vision
Tactile information

ABSTRACT

For maintaining heading direction while walking we heavily rely on vision. Therefore, walking in the absence of vision or with visual attention directed elsewhere potentially leads to dangerous situations. Here we investigated whether tactile information from the feet can be used as a (partial) substitute for vision in maintaining a stable heading direction. If so, participants should be better able to keep a constant heading direction on tactile pavement that indicates directionality than on regular flat pavement. However, such a pavement may also be destabilizing. Thus we asked participants to walk straight ahead on regular pavement, and on tactile pavement (tiles with ridges along the walking direction) while varying the amount of vision. We assessed the effects of the type of pavement as well as the amount of vision on the variability of the heading direction as well as gait stability. Both of these measures were calculated from accelerations and angular velocities recorded from a smartphone attached to the participants trunk. Results showed that on tactile pavement participants had a less variations in their heading direction than on regular pavement. The drawback, however, was that the tactile pavement used in this study decreased gait stability. In sum, tactile pavement can be used as a partial substitute for vision in maintaining heading direction, but it can also decrease gait stability. Future work should focus on designing tactile pavement that does provided directional clues, but is less destabilizing.

1. Introduction

Without sensory cues from vision or audition it is impossible to walk in a straight line [1]. While walking visual attention is often distracted when we are, for instance, looking at traffic signs, trying to retrieve something from our bag or are looking at a mobile device such as a cell phone. In fact mobile phone usage while walking has been shown to influence executive functions [2] and to cause inattentional blindness [3]. What is often overlooked is that while walking we continuously receive tactile information about the terrain via our feet. In case this tactile information indicates directionality, it potentially provides information about the heading direction. In this study we investigated if tactile information from the feet can be used as a (partial) substitute for vision in order to maintain a stable heading direction in an intuitive way.

In many countries tactile information in the ground is already available in the form of tactile pavement that is installed in public places, such as train stations, as a guide for the visually impaired [4–7]. In general, there are two types of tactile pavement: directional tiles that indicate the direction of travel, and warning tiles that indicate potential hazard or junction [4,8]. Since we were interested in the use of tactile information for maintaining heading direction, the tactile pavement type that indicates direction of travel provided us with a readily available stimulus. These tiles consist generally of long ridges in the walking direction. The material of the tiles and dimensions of the grooves vary between and even within countries (see Section 2 for specifics on the tiles used in this study).

While tactile information in the ground can be useful to indicate walking direction, a potential disadvantage of walking on an uneven ground surface is that it affects gait stability. For instance, there have been reports of changes in stepping pattern when walking over uneven ground, while head accelerations remained similar [9], and a similar effect has been reported for unilateral amputees [10]. Moreover, even walking over even ground that is compliant has been shown to reduce gait stability [11]. Thus, alterations in flooring may affect gait stability, which may be

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http://dx.doi.org/10.1016/j.gaitpost.2015.08.009
0966-6362/

unwanted side-effects of tactile information that can be used for navigation. While alterations of gait due to tactile pavement have been reported [12,13] to date, no studies have looked directly at the influence of tactile pavement on gait stability and the ability to maintain a stable heading.

The aim of this study was to assess to what extent tactile information from the feet can be used to maintain a stable heading direction in an intuitive way. If so, tactile information may be used for indicating walking direction for the general public not only for those with impaired vision. Therefore, we investigated how tactile pavement influences heading direction while at the same time monitoring gait stability in healthy sighted participants. To test whether tactile information can be used as a substitute for vision we varied the amount of visual information in a systematic way with goggles. If tactile information from the ground can be used to intuitively indicate directionality we expect that heading direction is less variable when walking on tactile pavement compared to when walking on regular pavement. However, because the tactile pavement that is considered in our study has grooves along the heading direction it likely causes disruptions in the lateral direction (the least stable direction in human gait, see [14]) potentially leading to a less stable gait pattern.

2. Methods

Twelve healthy volunteers (5 male, height: 1.77 ± 0.1 m; weight: 72.8 ± 11.4 kg; age: 21.5 ± 1.7 years; means $\pm$ SD) participated in the experiment, which was approved by the local ethical committee. All participants had normal or corrected to normal vision, did not use tactile pavement in their daily life, and wore sneakers during the experiment. All participants provided written informed consent.

In the Netherlands, the directional tiles are usually gray or white and contain grooves oriented in the walking direction. Although the tile types vary across different locations in the Netherlands, the tiles used in this study had a sinusoidal height pattern with amplitude of 5 mm. The tiles were 30 by 30 cm and had 7 grooves. Two rows of tiles were placed next to each other such that the width of the tactile path was 60 cm (see Fig. 1). This allowed participants to walk on the path with both feet.

Participants were instructed to walk in a straight line on either tactile- or regular pavement (Fig. 1A, length of pavement 38.4 m). The amount of visual information was manipulated using goggles (Fig. 1B). The combination of pavement type and amount of visual information created six conditions, each of which was performed three times (Fig. 1C). The order of conditions was counter-balanced over subjects, but such that tactile-, and regular pavement conditions alternated. When a participant stepped outside the path with both feet, the test-leader guided the subject back to the path. This will be referred to as an intervention.

Accelerations and angular velocities of the trunk were measured at approximately 100 samples/second (due to the nature of the measurement device, the sample frequency was not exactly 100 Hz at all times (see Fig. 2A)) by a smartphone attached to the back, using an application designed at the VU University. The range of the accelerometers in this smartphone (Samsung Galaxy S II) 1) was [-19.6133 to 19.6133] m/s^2, and that of the gyroscope [-8.726646 to 8.726646] rad/s and the resolution as 0.0047884034 m/s^2 for the accelerometers, and 0.00030543262 rad/s for the gyroscopes (range and resolution were obtained from the free app Sensor Box for Android). Examples of raw acceleration traces can be found in Fig. 2B.

All data were analyzed in MATLAB (version 7.12.0). Accelerations and angular velocities were first resampled to 100 Hz. The minimum amount of strides per trial was 17. Since outcome measures may be dependent on time-series length, we calculated outcome measures for the first 17 and last 17 strides of a trial, and then averaged. Variability of heading direction was assessed both by the number of interventions, as well as variability of heading direction (standard deviation of heading angle, obtained by integrating angular velocity in the horizontal plane). Gait stability was assessed by means of the local divergence exponent (λ_s) [15,16]. A state-space was reconstructed from time-normalized time-series of 3D accelerations and angular velocities, and 1 time delayed copy (25 samples delay, yielding a 12D state-space). Next, λ_s was calculated using standard procedures, and expressed as ln(divergence)/step [17]. Higher values of λ_s indicate decreased gait stability.

Repeated measures analyses of variance (rm-ANOVA) were used to test the effects of Pavement and Vision on variability of heading direction and gait stability as well as walking speed. SPSS (version 21) was used for statistical analyses and an α-level of 0.05 was considered significant. The exact *P*-levels are reported for all rm-ANOVAs as well as a measure of effect size (η_p^2). Whenever the Mauchly test indicated that the assumption of sphericity was violated, a Greenhous-Geisser correction was applied. If post hoc, pairwise comparisons were used, we report Bonferroni corrected *P*-levels to control for inflation of the familywise error rate. Means (medians) and standard deviations (inter-quartile ranges) were plotted, and exact values were reported in Supplementary Table S1.

3. Results

One participant's data had to be omitted from analysis, because the smartphone was not properly attached to the participant.

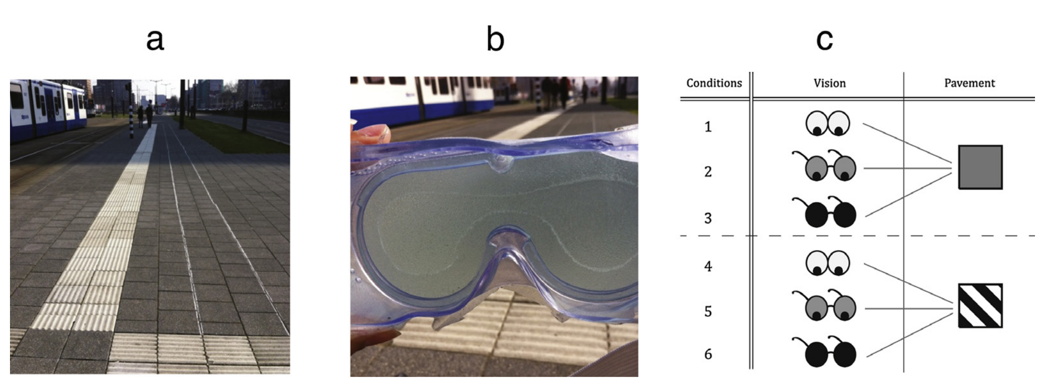

Fig. 1. (A) A picture of the path with regular pavement (lines of chalk marked the path) and tactile pavement. Both paths had a length of 38.4 m and a width of 0.6 m. The experiment was performed in a public place in Amsterdam (the Netherlands). (B) There were three levels of vision: full vision, reduced vision and no vision. Vision was reduced by means of goggles and the reduced vision is illustrated in the figure. During conditions with goggles, participants were not allowed to take the goggles off. (C) The three amounts of vision and the two types of pavement resulted in six experimental conditions.