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Impacts of using a head-worn display on gait performance during level walking and obstacle crossing

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A R T I C L E I N F O

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A B S T R A C T

Use of a head-worn display (HWD) may affect gait performance and increase slip and trip risks, though there is a lack of information on such effects. This study investigated how different display technologies (monocular and binocular HWDs, and a paper list) and visual information presentation modes affect gait performance. Twelve gender-balanced participants completed walking and obstacle crossing trials on a linear walking track under all experimental conditions and a baseline control (without using a technology). During these trials, information relevant to a simulated light assembly task was provided, as representative of a potential occupational application. Gait performance was assessed based on minimum foot clearance (MFC), required coefficient of friction, foot placement locations around the obstacle, and/or walking/obstacle crossing speed. Use of a HWD had no substantial effects on level walking performance. A more conservative/cautious obstacle crossing strategy was, however, observed with HWD use, including a decrease (~3%) in obstacle crossing speed (compared to the baseline). Gender-specific foot control strategies (lead foot MFC) were also observed that depended on the specific display technology and information modes. Foot placements around the obstacle were not influenced by use of the binocular HWD, yet a conservative strategy was observed with the monocular HWD.

1. Introduction

Wearable technology, such as "smart glasses" or more generally augmented reality head-worn displays (HWDs), has been drawing increasing attention, including for potential occupational use in sectors such as logistics (Reif and Günthner, 2009; Weaver et al., 2010) and maintenance/assembly (Caudell and Mizell, 1992). When using a HWD, the wearer can employ both hands freely while accessing information projected within their field of view, which is thus potentially beneficial in performing a work task. However, having a display in front of one (monocular) or both eyes (binocular) raises practical concerns, such as distraction and reduced situational awareness (Kim et al., 2016). HWDs can cause reduced visual performance (Longley and Whitaker, 2015), inaccurate depth perception (Drascic and Milgram, 1996), and less sensitive detection of unexpected events (Krupenia and Sanderson, 2006; Liu et al., 2009). Further, Mustonen et al. (2013) found that performing a cognitive task (working memory) administered via a monocular HWD negatively affects paced gait performance, as indicated by an increase in path overruns. Reading via a monocular HWD (vs. a handheld device) also required more time and was considered to be more demanding (Vadas et al., 2006).

In addition, there is broader evidence that an increase in attentional demands and/or cognitive distraction can negatively affect gait performance (e.g., Dubost et al., 2008; Bock and Beurskens, 2011; Soangra and Lockhart, 2017). Such effects could, in turn, increase the risks of slips, trips, and falls (STFs) especially in challenging environments (e.g., floor obstacles present). STFs are a major cause of occupational injuries and fatalities in many countries. In the U.S., for example, STFs accounted for ~ 28% of lost workday cases (BLS, 2016b) and ~17% of fatal occupational injuries (BLS, 2016a) in 2015. In the UK, ~25% of cases with more than seven lost workdays in 2016 were due to STFs (UNISON National, 2017). Previous work (e.g., Bentley, 2009; Chang et al., 2016; Leclercq et al., 2017) has identified multiple factors contributing to STFs, including working environments, organizational factors, job characteristics, and individual characteristics. Given the expanding interest in occupational use of HWDs, we believe there is a need to understand the potential impacts of HWD use on gait performance related to slip- and trip-related fall risks.

This exploratory study aimed to assess the influence of HWD use on gait performance during level walking and obstacle crossing. Specifically, and not limited to occupational implementations, using a HWD will likely involve evidence-based decision making regarding the type of HWD and methods for information presented on the display. We considered two different HWD types (binocular vs. monocular) and

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information-presentation modes (text- vs. graphic-based). The latter was included given that information-presentation mode can influence perceptual and information processes (Speier, 2006). Gait performance was assessed when participants concurrently processed information relevant to a simple assembly task during level waking or obstacle crossing. We hypothesized that HWD use would worsen gait performance and that this influence would be more pronounced during the more challenging obstacle crossing activity vs. level walking. We also hypothesized that the magnitude of adverse effects would depend on the specific HWD type, information-presentation mode used, and potential gender-related differences. The latter was considered since gender differences have been observed in gait and upper body kinematics during level walking (Chumanov et al., 2008; Mazzà et al., 2009), including greater hip abduction among females and greater head accelerations among males. Further, females and males exhibited different body turning preferences when navigating in a virtual environment while wearing a HWD (Bowman et al., 2002).

2. Methods

2.1. Participants

A convenience sample of 12 gender-balanced participants were recruited from the university and local community. Their mean (SD) age, stature, and body mass were 25.3 (6.0) yrs, 177.2 (6.2) cm, and 74.2 (8.3) kg, respectively for the males; and 30.2 (14.3) yrs, 164.2 (4.8) cm, and 55.8 (5.4) kg, respectively, for the females. All participants reported having normal or corrected-to-normal vision (with contact lenses only), and having no recent (past 12 months) or current musculoskeletal disorders or injuries. Prior to any data collection, participants gave written informed consent following procedures approved by the Virginia Tech Institutional Review Board.

2.2. Experimental design and procedures

We used a repeated-measures design to assess the effects of different technology types and information-presentation modes on gait performance during level walking and obstacle crossing. The three levels of *Technology Type* (*Tech Type*) were: a paper list, binocular HWD, and monocular HWD (Fig. 1). Two levels of *Information-presentation Mode* (*Info Mode*) were text- vs. graphic-based information that was required to complete a simulated assembly task using a Purdue Pegboard (Fig. 2). This assembly task involved pins, washers, and collars of a given quantity and in a given sequence.

Level walking and obstacle crossing trials were performed on a linear walking track (1.5 m wide × 15.5 m long). For both level walking and obstacle crossing trials, participants were asked to first stand at a starting position, walk across the track at a "purposeful" walking speed (Beringer et al., 2014), and cross any obstacle when it was presented as they would in the real-life situations. Participants completed the assembly task upon reaching the end of the track. Over the middle region of the walking track, information required to complete the assembly task was provided according to a given experimental condition. For obstacle crossing trials, a rectangular-shaped foam object was used (1.5 m wide × 5 cm long × 6 cm high), and was placed between two force platforms (AMTI, OR-6, Watertown, MA) embedded in the middle of the walking track.

Upon arrival to the laboratory, participants were provided identical model of shoes, in their own size, and were asked to do repeated trials of level walking and obstacle crossing on the gait track at their purposeful walking speed. These initial trials were done without using any of the noted technology types, serving as a baseline condition, and then for a total of at least 30 min under all experimental conditions for familiarization. During this initial familiarization, the starting foot position was adjusted for the baseline and each of the experimental conditions, to ensure that participants stepped on each of the two force platforms, without visible adjustments to their gait patterns. We marked the final starting foot positions on the walking track, and also marked the locations that were two steps ahead/after the first/second force platform. Only between these locations was visual information (required to complete the simulated assembly task) presented on a HWD, and which was controlled using a tablet computer that was wirelessly mirrored to the HWD. For the paper list condition, a "beep" sound was played when entering and leaving the region; participants were asked to look at the paper list when hearing the first beep, and were allowed to stop looking at any time before the second beep. Participants then completed the assembly task, based on the memorized task information. To ensure that participants paid attention to the information, we checked if the assembly task was completed correctly, and provided feedback to participants if otherwise.

After the familiarization period, participants completed level walking and obstacle crossing trials in the baseline and each of the experimental conditions. All conditions were replicated three times, and a minimum of 30 s rest was provided between both replications and conditions. For the baseline trials, the presentation order of level walking and obstacle crossing (namely, obstacle presence conditions) was alternated between participants. For the experimental trials, the presentation order of *Tech Type* was counterbalanced using 3 × 3 Balanced Latin Squares, and within a given *Tech Type* condition the order of *Info Mode* and obstacle presence conditions was counterbalanced using 4 × 4 Balanced Latin Squares.

2.3. Data collection and analysis

Triaxial ground reaction forces (GRFs) were sampled at 1 kHz from the two force platforms, and subsequently low-pass filtered (36 Hz cutoff; 6th order Butterworth; bidirectional). Bilateral foot kinematics were captured at 100 Hz, using a 10-camera optical motion capture camera (Vicon Motion Systems Ltd., Vero, Denver, CO), and were subsequently low-pass filtered (9 Hz cutoff; 4th order Butterworth; bidirectional). After the familiarization period, we placed passive reflective markers bilaterally, or in the mid-sagittal plane, over several anatomical landmarks: calcaneus, first and fifth medial metatarsal heads, second toe distal phalange, lateral and medial malleoli, anterior and posterior iliac superior spines. In addition, and based on Startzell and Cavanagh (1999), eight reflective markers were placed around the

Fig. 1. Technology types: paper list (Left; text font size = 18 pt.), commercially available binocular (Middle; Epson Moverio BT-200), and monocular head-worn display (HWD) (Right; Vuzix M100).