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The reduced lighting environment impacts gait characteristics during walking

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ABSTRACT

Objectives: This study aimed to investigate how different light intensities affect human gait patterns during walking. Humans rely on visual information from the surroundings to mediate foot placement and maintain balance during walking. The reduction of light, which diminishes visual input, is recognized as a contributing factor in the incidence of falling; however, such impact on gait characteristics has not been identified yet at different constrained levels of light intensities.
Methods: Twelve healthy adults were instructed to walk at their self-selected pace on a treadmill either in high or low lighting conditions. The light intensity during treadmill walking was reduced using a pair of goggles attached to different layers of window films. Three-dimensional spatiotemporal gait data were collected using a motion capture system.
Results: The significantly decreased stride length, stride time, double support time, and the significantly increased gait variability of stride length and stance time, were presented in the reduced lighting condition.
Conclusions: Overall, this study indicates that the lighting intensity impacts gait adjustments during walking. Underground workers navigating in a dim and constrained environment could alter their walking patterns that relate to falling accidents.
Relevance to industry: Slips, trips and falls are common accidents occurred in underground workers which correlate to the insufficient lighting condition. This study investigated the impact of different lighting conditions on gait adjustment which contributes to the safety of workers situating in a reduced lighting environment.

1. Introduction

Underground workers, such as coal miners or tunnel workers, perform their tasks under an insufficient lighting condition and exposed themselves to confined and hazardous environments (Mine Injury and Worktime Reports, 2013; Sammarco et al., 2010, 2012). Working in such restricted environments constrain underground workers' vision, posture, and mobility to the extent that they cannot react accordingly and the injury-induced accidents may take place (Peters et al., 2001). According to Mine Safety and Health Administration, slips, trips, and falls are the second leading cause of nonfatal injury occurrence among underground workers that results in days of restricted work activity (Mine Injury and Worktime Reports, 2013), and these injurious events may be caused by the reduced lighting condition (Sammarco et al., 2010, 2012).

To reduce slips, trips and falls, humans rely on self-perceptions to maintain their balance. Self-perceptions are the retrieving afferent information from the surroundings through the receptors of vision, vestibular system and somatosensory, which are processed and integrated into the cortex to generate a corresponding movement command for maintaining balance (Goldstein, 2010). Specifically, visual perception dominates over other perceptions to control human locomotion and mediate foot placement (Patla et al., 1999; Gibson, 1979), and controls human movement (Patla, 1998) in different lighting conditions.

Loss of the normal function of visual perception due to limited visual field or acuity could alter human movement or induce abnormal walking patterns (Helbostad et al., 2009). Peters et al.

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reported the outward environment such as seam height negatively affects miner's vision to detect hazards (Peters et al., 2001). The other study indicated that impaired contrast sensitivity of vision in older adults with maculopathy was associated with postural instability, slower walking velocity, reduced stride length and increased step width (Wood et al., 2009). It also indicated that the visual field impairments were associated with increased double-support time. Graci and colleagues used four different monocular occlusions to restrict the visual field and found that foot clearance increased, but step length and walking velocity decreased during over-ground walking (Graci et al., 2009).

Reduced lighting condition is one of the leading factors that increases fall incidences (Helbostad et al., 2009). Sammarco et al. investigated the effect of different miner cap lamps on hazard detection among varied healthy ages, and found that subject's response time is shorter with the assistance of LED-based cap lamp versus traditional incandescent illumination (Sammarco et al., 2010); they further compared different cap lighting effects on miner's standing postural control and confirmed that the reduced lighting condition directly decreased their stability (Sammarco et al., 2012). In addition, in a survey study conducted for underground workers of a transportation company, non-light-exposed working environment induced sleep disturbance in those workers; which can be seen as the indirect factor that leads to accidents during working (Leger et al., 2011). Delbaere and colleagues dimmed the indoor lighting condition and adjusted height of walking level also stated the increased fall-related concerns by observing the cautious gait pattern they adopted such as slower walking speed, shorter steps with increased cadence and double support time (Delbaere et al., 2009).

The aforementioned dim lighting-related studies were conducted only under fixed ambient lighting condition, how the different lighting intensity at a constrained environment impacts gait adjustments, however, remains unknown. To understand how underground workers adapt their gait to different lighting conditions across time in a constrained environment, studying the effect of varied lighting environments on human locomotion can lay the groundwork. Therefore, the purpose of this study was to investigate how the intensity of light at different levels influence human gait patterns during treadmill walking and to show the ability of how people adjust their gait patterns in different dim lighting environments. We hypothesized that people would alter their spatiotemporal gait characteristics while encountering a constrained environment such as walking under a dim lighting condition; in specific, the deviated gait patterns would be observed regarding the decreased stride length, increased step width, decreased stride time, and the increased variability of these gait characteristics.

2. Material and methods

2.1. Subjects

Twelve healthy adults (mean age = 24.4 ± 2.8 years; height = 179.0 ± 7.6 cm; mass = 74.7 ± 16.9 kg; leg length = 84.7 ± 5.5 cm; pelvic width = 25.64 ± 2.11 cm) were informed the process of the experiments, and signed the consent form approved by the Institutional Review Board in University of Nebraska Medical Center. Subjects were instructed to put on the prepared walking shoes according to their foot size.

2.2. Experimental protocol

This study was conducted in the Nebraska Biomechanics Core Facility in the University of Nebraska at Omaha where all participants firstly walked on a non-inclined treadmill (Bertec Corp. Columbus, OH) for a 5-min period of familiarization. Subsequently, they walked with their self-selected pace (the comfortable daily walking speed) for 2 min under three randomized lighting conditions. The perceived light intensity was manipulated using a pair of clear goggles (MSA Safety Works, Pittsburgh, PA), which were attached without (the control ambient lighting condition), with one layer, and with two layers of Gila® window film respectively (Solutia Inc. St. Louis, MO). We measured the light intensity under these three conditions (i.e. 7.9, 3.5, and 2.3 lux respectively) by pointing the Gossen Luna Pro light meter (Nürnberg, Germany) against the goggles where was similar to the eyes that received the light penetrating through it. The range of the varied light intensity can be defined as a moderate to dim lighting condition (Brooke-Wavell et al., 2002), and which met the minimal lighting requirement of performing a major portion of mining task (Lewis, 1986).

To control the gaze direction during walking and simulate the dim lighting environment of underground working condition, a fixed virtual tunnel was rear projected on a three-fold screen in front of the subject, and subjects were instructed to look at the exit of the tunnel (i.e. the focus of expansion) during walking (Fig. 1). Also, a non-transparent tape was attached at the both sides of goggles to constrain other visual information entering from the peripheral visual field. To eliminate the carry-over effect of adapting previous lighting conditions (e.g. the sensitivity and capability of eyes to get adapted in the darkness) (Mine Injury and Worktime Reports, 2013; Goldstein, 2010), the indoor lights were all switched on as a wash-out period when subjects were taking a 2-min break.

Three-dimensional kinematical gait data were collected using the NDI motion capture system (Northern Digital Inc, Waterloo, Canada) at 100 Hz. Two rigid bodies with six active infrared-emitted markers were attached on both subject's lateral feet; the locations of toe, heel, the first and fifth metatarsal heads of both limbs were digitized as virtual landmarks. The following spatiotemporal gait characteristics of subjects' dominant leg were processed using MATLAB program (MathWorks Inc. Natick, MA): stride length (distance between two consecutive steps of the same heel), step width (distance between two heels), stride time (the duration of two consecutive heel strikes on the same side), stance time (the duration that single leg on the ground), and double support time (the duration that two legs on the ground simultaneously). In addition, the stride length was normalized by the subjects' leg length whereas the step width was normalized by the width subjects' pelvic width (distance between right and left anterior superior iliac spines). Furthermore, the gait variability in terms of coefficient of variation (CV) was evaluated among the spatiotemporal gait characteristics. The differences between experimental conditions (reduced light intensity) and the control condition of all spatiotemporal gait characteristics including CVs were computed and presented as the changes in percentage (%).

2.3. Statistical analysis

A one-way (three factors of light intensity) ANOVA with repeated measure was applied to examine how different light intensities impact on gait characteristics using the SPSS 18.0 (IBM Corp. Armonk, NY). The multiple comparisons with Bonferroni corrections were performed if a significant main effect was found. To compare the percentage changes from the control condition between the two-layer or one-layer condition, the paired *t*-test was used to examine if any significant change exists. The significant level (α) of all the statistical analyses was set at 0.05.

3. Results

Light intensity showed the significant main effect on