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The effects of shoe traction and obstacle height on lower extremity coordination dynamics during walking

Leslie Decker[a], Jeremy J. Houser[c], John M. Noble[a], Gregory M. Karst[d], Nicholas Stergiou[a,b,*]

[a] Nebraska Biomechanics Core Facility, University of Nebraska at Omaha, 6001 Dodge Street, Omaha, NE 68182-0216, USA
[b] Environmental, Agricultural and Occupational Health, College of Public Health, University of Nebraska Medical Center, 987850 Nebraska Medical Center, Omaha, NE 68198-7850, USA
[c] Department of Health and Exercise Sciences, School of Health Sciences and Education, Truman State University, 212 Pershing Building, 100 E. Normal St., Kirksville, MO 63501, USA
[d] Division of Physical Therapy Education, University of Nebraska Medical Center, 984420 Nebraska Medical Center, Omaha, NE 68198-4420, USA

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ABSTRACT

This study aims to investigate the effects of shoe traction and obstacle height on lower extremity relative phase dynamics (analysis of intralimb coordination) during walking to better understand the mechanisms employed to avoid slippage following obstacle clearance. Ten participants walked at a self-selected pace during eight conditions: four obstacle heights (0%, 10%, 20%, and 40% of limb length) while wearing two pairs of shoes (low and high traction). A coordination analysis was used and phasing relationships between lower extremity segments were examined. The results demonstrated that significant behavioral changes were elicited under varied obstacle heights and frictional conditions. Both decreasing shoe traction and increasing obstacle height resulted in a more in-phase relationship between the interacting lower limb segments. The higher the obstacle and the lower the shoe traction, the more unstable the system became. These changes in phasing relationship and variability are indicators of alterations in coordinative behavior, which if pushed further may have lead to falling.

1. Introduction

Injuries associated with slips, trips and falls continue to pose a significant burden to society both in terms of human suffering and economic losses (Grönqvist and Roine, 1993; Kemmlert and Lundholm, 1998; Leamon and Murphy, 1995; Manning et al., 1988; National Safety Council, 1995). According to statistics from the Health and Safety Executive (HSE), slips and trips are the single most common cause of injuries at work, and account for over a third of all major work injuries. In the US, falls represent 19% of all nonfatal occupational injuries in 2001, and 13% of fatal occupational injuries in 2002 (Burnfield and Powers, 2006). The annual direct cost occupational injuries due to slips, trips and falls in the US have been estimated to be in excess of 6 billion US dollars (Courtney et al., 2001), and a cause of serious public health problem with costs expected to exceed $43.8 billion by the year 2020 in the US alone (Englander et al., 1996).

Both slips and trips result from unintended or unexpected changes in the contact between the feet and the walking surface. Thus, conventional biomechanical analyses (i.e., gait analysis) have been used to investigate human factors that cause slips, trips, and falls and their complex interaction with environmental factors (Moyer et al., 2006; Petrarca et al., 2006). Human factors include gait biomechanics, expectation, the health of the sensory systems (i.e., vision, proprioception, and vestibular) and the health of the neuromuscular system (Moyer et al., 2006). Among the most important environmental factors that could potentially cause instability during walking are the presence of obstacles and the loss of traction between the shoe sole and floor surface (Cohen and Compton, 1982). Therefore, numerous studies have investigated the effect of obstacle perturbations during walking (Begg et al., 1998; Chen et al., 1994; Chen and Lu, 2006; Chou and Draganich, 1997; Jaffe et al., 2004; McFadyen and Prince, 2002; Patla et al., 1991; Patla and Rietdyk, 1993; Petrarca et al., 2006; Sparrow et al., 1996). However, this research has focused on the approach to an obstacle by collecting gait data of the trailing and leading limb while negotiating the obstacle. In addition, there have been numerous studies that have used biomechanics of gait to examine the shoe–floor interface to understand slips (Burnfield and Powers, 2006; Bring, 1982; Cham and Redfern, 2001, 2002a,b; Gao and Abeysekera, 2003; Gao et al., 2004; James, 1980; Lockhart et al., 2003, 2005; Perkins,

* Corresponding author. Nebraska Biomechanics Core Facility, University of Nebraska at Omaha, 6001 Dodge Street, Omaha, NE 68182-0216, USA. Tel.: +1 402 5543247; fax: +1 402 5543693.
E-mail address: nstergiou@mail.unomaha.edu (N. Stergiou).

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1978; Perkins and Wilson, 1983; Redfern and Dipasquale, 1997; Strandberg, 1983; Standberg and Lanshammar, 1981; Winter, 1991). However, limited attention was devoted to the combined effect of obstacles and low friction shoe–floor interface on the landing strategies adopted to avoid slipping after obstacle clearance (Patla and Rietdyk, 1993; Bentley and Haslam, 1998; Leclercq, 1999). Two main categories of adaptive strategies are used when an individual encounters both an obstacle and a more slippery zone: "*strategies of avoidance*" that consist of modifying walking patterns in order to step over the obstacle, and "*strategies of accommodation*" that consist of the modification of walking patterns in order to adapt to the low friction footwear–floor interface (Patla, 1991). The question thus arises: how these strategies interact and what kinds of corrective reactions occur in an attempt to avoid a fall.

Conventional kinematic gait analysis of slip, trip, and fall events relies on angular position–time, velocity–time, or angle–angle presentations (e.g. Cham and Redfern, 2001; Fong et al., 2005). However, such presentations do not reveal the direct relationship between velocity changes and position (Burgess-Limerick et al., 1993; Kurz et al., 2005; Van Uden et al., 2003; Winstein and Garfinkel, 1989). It is important to evaluate this relationship since the joint and muscle proprioceptors, and the visual and vestibular receptors provide sensory feedback on both velocity and position. This means that the multiple sensory cues will potentially compete for governance of the evoked behavioral response (Misiaszek, 2006). Furthermore, quantification of interjoint (e.g. thigh–shank) coordination is very difficult with the above-mentioned presentations (Burgess-Limerick et al., 1993; Davids et al., 2003; Scholz, 1990; Scholz and Kelso, 1989; Sparto et al., 1997). Coordination analysis using relative phase dynamics can solve the above problems and provide a window of particular types of causal motor control processes that are not usually revealed by conventional time-based plots (Gottlieb et al., 1983; Hamill et al., 1999; Heiderscheit et al., 1999; Kurz et al., 2005; Kwakkel and Wagenaar, 2002; Sparto et al., 1997; Van den Berg et al., 2000; Van Uden et al., 2003; Winstein and Garfinkel, 1989). Relative phase dynamics utilizes the displacements and velocities of the segments that surround a joint to quantify the joint's coordination. For example, the continuous relative phase, a measure from relative phase dynamics, quantifies the coordination between the shank and thigh segments that compose the knee joint. Such a measure is appealing for quantifying signs of gait instability because it can reveal the compensatory reactions evoked in the lower extremity coordination patterns that may be due to changing task (obstacle clearance) and environmental (low friction) demands.

Therefore, the purpose of this study was to use a coordination analysis to investigate the effects of shoe traction and obstacle height on lower extremity coordination during walking to better understand the control strategies adopted to avoid slippage following obstacle clearance in normal young adults. In this study, we examined the intralimb phasing relationships between the foot, the shank and the thigh of the landing limb (Kurz et al., 2005). We hypothesized that stepping over obstacles with low shoe traction will challenge the motor control of the neuromuscular system and will affect intralimb phasing relationships. In this study, obstacle height was adjusted to percentages (0%, 10%, 20%, and 40%) of limb length to ensure that individuals of different heights would make the same qualitative adaptation in going over obstacles.

2. Methods

2.1. Participants

Ten healthy young adult males between the ages of 18 and 35 from the general student community of the University of Nebraska at Omaha volunteered as participants (age: 25.8 ± 4.29 years; body mass: 82.8 ± 8.25 kg; height: 179.6 ± 6.34 cm; leg length – as measured from the right anterosuperior iliac spine to the right lateral malleolus: 95.6 ± 4.49 cm; shoe size: 10). All participants were without appreciable leg length discrepancy and had no injuries or abnormalities that would affect their gait. Prior to testing, each participant provided an informed consent approved by the University of Nebraska Medical Center Institutional Review Board.

2.2. Instrumentation

A sagittal view of the right lower extremity was obtained for all trials using a Panasonic WV-CL350 (Osaka, Japan) video camera with a sampling frequency of 60 Hz. The video camera was located 8-m perpendicular to the walking pathway. A zoom lens (COSMICAR TV, 8–48 mm zoom lens, COSMICAR/PENTAX Precision Co., Tokyo, Japan) was used in conjunction with the video camera to optimize image size and minimize perspective error. A light source (Pallite VIII using eight ELH 300W tungsten-halogen projection lamps at 120 VAC) was mounted with the camera lens in the center of the ring to better illuminate the reflective markers.

Reflective markers were positioned on the participant's right lower extremity, here referred to as the leading limb (i.e., the limb crossing the obstacle first). All positional markers were placed on the participants by the same examiner. Sagittal plane marker placement was as follows: (1) mid-distance between the greater trochanter of the hip and the lateral joint line of the knee, (2) lateral joint line of the knee, (3) lateral malleolus, (4) outsole of the shoe approximately at the bottom of the calcaneus, and (5) outsole of the shoe approximately at the fifth metatarsal head. An additional marker was positioned at the obstacle to assist in determining the location of the obstacle in the field of view.

The video images were stored on SVHS video tapes via a Panasonic AG-1970P video camera recorder, which was interfaced with a Magnavox TV for an instant qualitative evaluation of the video recording. The video data were transformed to digital format and digitized via the PEAK MOTUS video system (Peak Performance Technologies, Inc., Englewood, CO). A single camera was used because sagittal view measures of walking correspond well in two- and three-dimensions (Doriot and Cheze, 2004; Eng and Winter, 1995). GRF data were also collected using a force platform. These data were presented elsewhere (Houser et al., 2008).

Two pairs of men's shoes (Pro-wing Joggers, size 10), with homogenous midsoles and rubber outsoles, were used in this experiment. The same shoes and shoe size were used for all participants to minimize any effects from the shoe characteristics on the results of the study. The shoe size of 10 was selected because it is the most common shoe size among males in the USA. To decrease the COF of one pair of the shoes, without significantly modifying their weight, flexibility and general performance, 88 metallic one-half inch diameter disc thumbtacks were inserted into the outsole of both the left and right shoe. The thumbtacks were carefully placed in order to ensure that no part of the actual shoe was able to contact the ground during walking locomotion. They were also roughed and cleansed to expose the metal originally covered with enamel. The thumbtacks increased the weight of the shoes by 25 g (475 g without the tacks vs. 500 g with the tacks). The pair with the high traction had dynamic COF (DCOF) of 0.7 and static COF (SCOF) of 0.8. The pair with the low traction had DCOF of 0.3 and SCOF of 0.35. The two selected tractions were based upon previous literature (Perkins, 1978; Denoth, 1989) and pilot test work suggesting the high traction pair was a very safe shoe, while the low traction pair a borderline safe shoe. Both high and low traction shoes were roughed with 20 passes of the 100 grit sand