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Identifying trippers and non-trippers based on knee kinematics during obstacle-free walking

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ABSTRACT

Trips are a major cause of falls. Sagittal-plane kinematics affect clearance between the foot and obstacles, however, it is unclear which kinematic measures during obstacle-free walking are associated with avoiding a trip when encountering an obstacle. The purpose of this study was to determine kinematic factors during obstacle-free walking that are related to obstacle avoidance ability. It was expected that successful obstacle avoidance would be associated with greater peak flexion/dorsiflexion and range of motion (ROM), and differences in timing of peak flexion/dorsiflexion during swing of obstacle-free walking for the hip, knee and ankle. Three-dimensional kinematics were recorded as 35 participants (young adults age 18–45 (N = 10), older adults age 65+ without a history of falls (N = 10), older adults age 65+ who had fallen in the last six months (N = 10), and individuals who had experienced a stroke more than six months earlier (N = 5)) walked on a treadmill, under obstacle-free walking conditions with kinematic features calculated for each stride. A separate obstacle avoidance task identified trippers (multiple obstacle contact) and non-trippers. Linear discriminant analysis with sequential feature selection classified trippers and non-trippers based on kinematics during obstacle-free walking. Differences in classification performance and selected features (knee ROM and timing of peak knee flexion during swing) were evaluated between trippers and non-trippers. Non-trippers had greater knee ROM ($P = .001$). There was no significant difference in classification performance ($P = .193$). Individuals with reduced knee ROM during obstacle-free walking may have greater difficulty avoiding obstacles.

1. Introduction

Achieving adequate foot clearance is crucial for preventing trips, one of the greatest causes of falls (Berg, Alessio, Mills, & Tong, 1997; Blake et al., 1988; Overstall, Exton-Smith, Imms, & Johnson, 1977; Tuunainen, Rasku, Jantti, & Pyykko, 2014; Robinovitch et al., 2013; Heijnen and Rietdyk, 2016). Foot clearance can be accounted for by the sagittal plane motion of the lower extremity joints (Winter, 1992). While individuals may employ different strategies to achieve adequate foot clearance (Little, McGuirk, & Patten, 2014; Levinger et al., 2012), each strategy for avoiding an obstacle ultimately relies on the magnitude of lower extremity joint

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angles and the timing of the joint motion. Since changes in the sagittal plane ankle, knee and hip angles individually affect foot clearance throughout swing phase of gait (Winter, 1992; Gates, Wilken, Scott, Sinitski, & Dingwell, 2012; Schulz, 2011; Schulz, Lloyd, & Lee, 2010; Moosabhoy and Gard, 2006), deficits in the magnitude of these joint motions may contribute to an inability to avoid obstacles while walking. Likewise, reduced time to avoid an obstacle, perhaps due to a shorter swing time, shorter distance in the approach between the foot and obstacle, or faster walking speed, may also result in reduced foot clearance (Chou and Draganich, 1998). This is particularly relevant if an individual's gait pattern during obstacle-free walking is not conducive to avoiding obstacles that appear suddenly, such as a previously unseen curb or a pet that darts into the walking path.

Just as the prevalence of falls increases with age (Talbot, Musiol, Witham, & Metter, 2005) or disability (Forster and Young, 1995; Wagner, Phillips, Hunsaker, & Forducey, 2009; Mackintosh, Hill, Dodd, Goldie, & Culham, 2005), the risk of tripping is different among certain demographic groups. Healthy young adults reported on average at least one slip or trip per week, with only 5% of those perturbations leading to a fall (Heijnen and Rietdyk, 2016). On the other hand, older adults are more likely to trip than young adults (Garman, Franck, Nussbaum, & Madigan, 2015), and have a greater risk of contacting an obstacle while walking, likely related to longer reaction times than young adults (Chen, Ashton-Miller, Alexander, & Schultz, 1994). Stroke survivors may have motor impairments that limit foot clearance during walking (Batchelor, Mackintosh, Said, & Hill, 2012). In particular, those who have experienced a stroke have been shown to exhibit less overall limb shortening, with maximal limb shortening occurring later in the gait cycle (Little, McGuirk, & Pattern, 2014). Thus, the kinematic factors that influence obstacle avoidance ability may be related to age or disability status.

Despite the obvious consequences of inadequate foot clearance and the incidence of trips, it is unclear which factors during obstacle-free walking are specifically related to the ability to avoid obstacles that appear suddenly. These factors may manifest as specific joint kinematics during obstacle-free walking that influence foot clearance in the presence of an obstacle, and these factors may be more pronounced among certain demographic groups. By investigating the walking patterns of stroke survivors as well as older adults with and without a history of falls and young adults, the purpose of this study was to determine the sagittal plane kinematics during obstacle-free walking that are related to the ability to avoid an obstacle that appears suddenly. It was expected that the stroke survivors and older adults with a history of falls would not be able to avoid the obstacle, and participants who were able to avoid an obstacle would have different obstacle-free gait characteristics than those who were not able to avoid the obstacle. In particular, it was projected that successful obstacle avoidance would be associated with greater peak hip and knee flexion, ankle dorsiflexion, and sagittal plane range of motion during swing for the lower extremity joints. Additionally, differences in timing of peak hip and knee flexion and ankle dorsiflexion during swing were expected.

2. Methods

2.1. Participants

The study protocol was approved by the University of Wisconsin-Milwaukee Institutional Review Board, and all participants provided informed consent. Thirty-five community-dwelling participants included young adults age 18–45 (N = 10), older adults age 65+ without a history of falls (N = 10), older adults age 65+ who had fallen in the last six months (N = 10), and individuals who had experienced a stroke more than six months earlier (N = 5) (Table 1). A fall was defined as unintentionally coming to rest on the ground (Senden, Savelberg, Grimm, Heyligers, & Meijer, 2012). All participants were able to walk without an assistive device for five minutes at a time. Inclusion was limited to participants with a Mini-Mental State Examination score greater than 22 (Savin, Morton, & Whitall, 2014). The participants with chronic stroke completed the lower extremity sub-scale of the Fugl-Meyer assessment, which has a range of possible scores of 0–34 (Sanford, Moreland, Swanson, Stratford, & Gowland, 1993; Sullivan et al., 2011).

2.2. 3D motion capture

Each participant was provided a pair of standard laboratory shoes (Saucony Jazz, Lexington, MA) and tight-fitting shorts.

Table 1
Participant Characteristics.

	Young Adult	Older Adult – Non-faller	Older Adult – Faller	Stroke
N	10	10	10	5
Age (range), yr	30.5 (22–44)	71.9 (65–87)	75.3 (66–91)	61.6 (40–83)
Height (SD), m	1.74 (0.14)	1.68 (0.08)	1.72 (0.12)	1.68 (0.10)
Weight (SD), kg	76.0 (18.1)	75.9 (16.2)	86.3 (23.0)	82.6 (13.4)
Sex	5M, 5F	3M, 7F	5M, 5F	2M, 3F
Number of Falls 6 Months (range)	0.1 (0–1)	0	1.4 (1–3)	0.4 (0–1)
Mini Mental State Exam (range)	29.6 (28–30)	29.3 (28–30)	28.6 (27–30)	27.6 (24–30)
LE Fugl-Meyer (range)	–	–	–	24.6 (17–31)
Affected Side	–	–	–	3 R, 2 L
Type of Stroke	–	–	–	5 ischemic
Time since stroke onset (range), mo	–	–	–	43.2 (10–120)

Note. SD = standard deviation; LE = lower extremity.