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Dual-task walking over a compliant foam surface: A comparison of people with transfemoral amputation and controls

Sara J. Morgan*, Brian J. Hafner, Valerie E. Kelly

Department of Rehabilitation Medicine, University of Washington, United States

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ABSTRACT

People with lower limb amputation are unable to reliably sense ground characteristics due to compromised sensory inputs from the missing limb. As a result, they may rely on compensatory strategies, such as use of cognitive resources, when walking over complex surfaces. This study examined interactions between cognition and walking over a compliant surface in 14 people with transfemoral amputation (TFA) and 14 controls using a dual-task paradigm. Walking was assessed with quantitative motion analysis in both single-task (walking alone) and dual-task (walking while performing a cognitive task) conditions over a compliant foam surface. Outcomes were walking speed, step width, step time asymmetry, step time variability, and the speed and accuracy of cognitive task performance. For each outcome, effects of task (single-task, dual-task) and group (TFA, control) were examined with repeated-measures analysis of variance. No significant group-by-task interactions were observed for cognitive task performance. A significant group-by-task interaction for step time asymmetry indicated that participants with TFA increased temporal asymmetry in dual-task relative to single-task conditions, while control participants maintained symmetrical gait. The addition of a concurrent cognitive task did not differentially affect other aspects of gait between groups. Significant main effects of group for all walking outcomes indicated that participants with TFA walked slower, with wider, more asymmetric, and more variable steps than controls. Results suggest that gait quality degrades in challenging dual-task conditions for people with TFA, but not controls, consistent with the idea that people with TFA may use increased cognitive resources to control walking in complex environments.

1. Introduction

Lower limb amputation profoundly alters physical structures and neural systems that enable smooth and efficient control of walking. Prosthetic limbs restore ambulatory mobility in people with amputation, but even state-of-the-art prosthetic technologies such as microprocessor-controlled prosthetic knees do not adequately restore peripheral sensory or motor functions. Peripheral sensory feedback and motor control pathways are critical to the neural control of walking, particularly in challenging environments. For example, when surface characteristics change, sensory inputs signal the need for rapid gait adaptations to maintain safe and stable walking [1]. In the absence of sensory inputs from and motor outputs to the prosthetic limb, persons with amputation may employ various compensatory strategies, such as adopting a conservative gait pattern or allocating additional cognitive resources to walking. Increased concentration during walking is commonly reported by persons with amputation, including those with transfemoral amputation (TFA) [2,3]. However, objective studies to determine the differential effects of a concurrent cognitive task on walking between people with and without TFA using dual-task methods have not substantiated these reports [4–6].

Differences between perceived and measured dual-task walking performance in people with TFA may be due to experimental walking conditions used in prior studies. Previous studies have primarily assessed dual-task performance under relatively simple walking conditions, such as walking over a firm surface [4,6] or on a treadmill [5]. More complex environments, like walking over uneven or compliant surfaces, may present a greater challenge for people with TFA, who must rely on limited peripheral sensation to accommodate the changing characteristics of the walking surface. When walking over challenging surfaces, people with TFA may increase reliance on cognitive resources to compensate for peripheral sensorimotor deficits and maintain safe and stable walking. Indeed, walking on complex surfaces like ice, sand, and snow has been identified by people with TFA requiring additional concentration [6].

The purpose of this research was to examine the effects of a

* Corresponding author at: University of Washington, Department of Rehabilitation Medicine, 1959 NE Pacific Street, Box 356490, Seattle, WA 98195, United States.
E-mail address: sjmorgan@uw.edu (S.J. Morgan).

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concurrent cognitive task on walking performance across a compliant surface in people with TFA compared to age- and sex-matched controls. We selected a foam surface that would distort participants' peripheral sensory feedback in a manner similar to surfaces encountered in daily life (e.g., sand and grass). We hypothesized that under these conditions, a concurrent cognitive task would disproportionately affect walking in people with TFA compared to matched controls.

2. Methods

2.1. Participants

People with TFA and people without amputation (control group) were recruited. Eligibility criteria for all participants were: (1) 18 years of age or older, (2) able to walk without an assistive device for 15 min, (3) able to negotiate ramps and stairs, and (4) no comorbidities impacting walking, cognition, or the ability to complete the protocol. For people with TFA, additional eligibility criteria were: (5) unilateral amputation, (6) most recent amputation surgery at least one year prior, (7) prosthesis that was comfortable for at least three months, and (8) use of a microprocessor-controlled prosthetic knee. Participants in the control group were recruited to match the age (within 5 years) and sex of those in the TFA group. This study was approved by an Institutional Review Board and informed consent was obtained from all participants.

2.2. Procedure

Participants were recruited through flyers at prosthetic clinics in the XXX metro area. Interested and eligible participants attended a single, 2-h testing session in a motion analysis laboratory. Self-reported demographic and health information were collected to characterize participants. Participants completed the 5-item response version of the Activities-specific Balance Confidence (ABC) Scale, a self-report measure of balance confidence during 16 daily activities [7,8], and the Montreal Cognitive Assessment (MoCA), a brief tool for screening global cognition [9]. Participants with TFA also provided details about their amputation and prosthetic history.

2.2.1. Cognitive task

Participants performed an auditory analogue of the Stroop test under single-task (while seated) and dual-task (while walking over the foam surface) conditions. For this task, participants listened to auditory stimuli that consisted of the words "high" and "low" said in a high or low pitch and responded by naming the pitch as quickly and as accurately as possible. Recorded stimuli were presented in blocks (20 stimuli per block for practice, 8 stimuli per block for single- and dual-task conditions). Stimuli were presented approximately every 3 s. A 0–1 s random delay was encapsulated in the 3-s intervals to prevent temporal entrainment of steps with stimulus presentation during dual-task conditions. Participants were first oriented to the task and provided three practice blocks to mitigate potential learning effects. Two blocks each were performed in the single-task and dual-task conditions. Stimuli and responses were collected for later processing using custom hardware and software [6]. Cognitive task performance was assessed using response latency (the time between stimulus onset and response onset) and response accuracy (the percent of correct responses).

2.2.2. Walking task

Participants walked at their self-selected speed over a low-density, closed-cell foam surface (Fig. 1) located centrally along an 8.8-m walkway. Similar foam surfaces are used in clinical assessments to distort somatosensory input and challenge sensory integration [10]. Walking was performed under single-task (walking without performing a cognitive task) and dual-task (walking while performing a cognitive task) conditions. For all walking conditions, participants performed at least one 10-s practice trial to become familiar with the foam surface and mitigate learning effects. Following the practice trial, participants performed two, 24-s walking trials for each walking condition. Participants walked back-and-forth over the foam mat continuously throughout each trial. During the dual-task condition, the cognitive task began immediately after participants started walking and ran continuously throughout the 24-s trials. Participants were asked to focus on the cognitive task to reduce variability in task prioritization among participants. A gait belt was worn by all participants, and a physical therapist or prosthetist walked with participants if they appeared unstable.

Retroreflective markers were placed on each participant's trunk, pelvis, bilateral arms, and bilateral legs. For participants with TFA, additional markers were placed on the prosthetic socket, knee, pylon, and foot. An eight-camera Qualisys Motion Capture System (Gothenburg, Sweden) was used to collect three-dimensional marker position data along the central 4 m of the foam mat with a capture rate of 120 Hz. Qualisys Track Manager and Visual 3D motion analysis software (C-Motion, Inc., Rockville, MD) were used to process, filter, and calculate stride and step characteristics from position data.

Walking outcomes for this study were speed, step width, step time asymmetry, and step time variability. Walking speed is a valid, reliable, and sensitive measure of progression [11]. Step width is a measure of postural stability [12]. Step time asymmetry, which is often pronounced in people with TFA [13], can be used to assess gait quality (i.e., an increase in within-participant asymmetry across conditions indicates worse gait quality). Step time variability was included because temporal variability has been found to be sensitive to dual-task conditions in various populations, including healthy older adults [14].

2.3. Statistical analysis

Means and standard deviations were calculated for all variables (IBM SPSS Statistics v19.0, Armonk, USA). Paired *t*-tests were used to assess potential between-group differences in participant demographic and health characteristics. Between-group differences in the effects of a concurrent cognitive task on walking were examined statistically for all outcomes using repeated-measures analysis of variance (ANOVA) with one within-subject factor (task: single-task, dual-task) and one between-subject factor (group: TFA, control). Significant group-by-task interactions would indicate that a concurrent cognitive task differentially affected walking or cognitive task performance in people with TFA compared to matched controls. An alpha level of 0.05 was used for all statistical tests.

3. Results

3.1. Participants

Participants with TFA (n = 14) and matched controls (n = 14) were similar in most characteristics (Table 1), including height ($p = 0.61$), weight ($p = 0.71$), and number of comorbid conditions ($p = 1.0$). However, participants with TFA had significantly lower MoCA scores ($p = 0.006$), worse ABC scores ($p = 0.003$), and more self-reported falls per year ($p = 0.009$) than control participants. The majority of participants with TFA underwent amputation as a result of trauma (n = 8), followed by tumor (n = 3), infection (n = 2) and vascular disease (n = 1). Results of single- and dual-task walking over a firm surface in this group of participants has been previously published [6].

3.2. Cognitive task

A main effect of task ($p = 0.02$) for response latency indicated that longer latencies were observed in the dual-task (walking on foam) compared to single-task (seated) condition for both groups. In addition, a main effect of group ($p = 0.03$) indicated that, overall, people with