Human Movement Science 58 (2018) 41–54

Contents lists available at ScienceDirect

Human Movement Science

journal homepage: www.elsevier.com/locate/humov

Full Length Article

Trunk and pelvic dynamics during transient turns among individuals with unilateral traumatic lower limb amputation

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A R T I C L E I N F O

Keywords:
Lower limb loss
Coordination
Momentum
Turns
Biomechanics

A B S T R A C T

Prior work has identified alterations in trunk-pelvic dynamics with lower limb amputation (LLA) during in-line walking; however, evaluations of other ambulatory tasks are limited. Turns are ubiquitous in daily life but can be challenging for individuals with LLA, prompting additional or unique proximal compensations when changing direction, which over time may lead to development of low back pain. We hypothesized such proximal kinematic differences between persons with and without LLA would exist in the sagittal and frontal planes. Three-dimensional trunk and pelvic kinematics, translational and rotational momenta, and coordination phase/variability were compared among eight persons with unilateral LLA (4 with transfemoral amputation and 4 with transtibial amputation), and five uninjured controls, who performed 90-degree turns to the left (n = 10) and right (n = 10). Participants self-selected the turn strategy (i.e., step vs. spin) and pivot limb in response to verbal cues regarding when and which direction to turn. Coordination variability and translational angular momenta did not differ between groups in either turn type. During spin turns, frontal rotational angular momenta were larger and frontal trunk-pelvis range of motion was smaller among persons with vs. without LLA. During step turns, pelvis leading transverse coordination was more frequent, frontal trunk rotational angular momentum was smaller, and sagittal pelvis range of motion was larger among persons with vs. without LLA. Altered and task-dependent modulation of trunk-pelvic dynamics among persons with LLA provides additional support for a potential link between repeated exposures to altered trunk-pelvic dynamics with elevated low back pain risk.

1. Introduction

Persons with lower limb amputation (LLA) often walk with compensatory movement strategies involving a prominent reliance on the trunk and pelvis (Goujon-Pillet, Sapin, Fodé, & Lavaste, 2008). Altered kinematic features and coordination of these two segments have been associated with elevated demands on the low back (Hendershot & Wolf, 2014), increased inter-segmental rigidity (Russell Esposito & Wilken, 2014), and larger trunk muscular forces and spinal loads (Shojaie, Hendershot, Wolf, & Bazrgari, 2016; Yoder, Petrella, & Silverman, 2015). These altered loads and asymmetric trunk-pelvis kinematics among persons with LLA have been suggested as key factors in disc degeneration and passive ligamentous strain potentially leading to development of low back pain (LBP; Devan, Hendrick, Ribeiro, Hale, & Carman, 2014; Gailey, Allen, Castles, Kucharik, & Roeder, 2008). As such, differences in trunk/pelvis kinematics between persons with and without LLA have been characterized during in-line walking (Goujon-Pillet et al.,

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https://doi.org/10.1016/j.humov.2018.01.006
Received 14 April 2017; Received in revised form 6 January 2018; Accepted 9 January 2018
0167-9457/ Published by Elsevier B.V.

2008; Hendershot & Wolf, 2014; Morgenroth et al., 2010). Yet, in-line walking is but one movement among many required for functional independence. Thus, characterizing the extent to which persons with LLA utilize proximal compensations during other (perhaps more demanding) tasks/activities of daily living would facilitate a more comprehensive understanding of biomechanical contributors to LBP risk.

Transient (i.e., non-steady-state) tasks embedded within in-line walking are ubiquitous and often necessary to adequately navigate an environment. Turns, in particular, account for approximately half of daily steps (Glaister, Bernatz, Klute, & Orendurff, 2007; Sedgeman, Goldie, & Iansek, 1994). Biomechanically, turns require a redirection of the body's center of mass, typically as a change in direction between 76 and 120 degrees (Sedgeman et al., 1994) executed using either a step (turn direction is contralateral to pivot leg) or spin strategy (turn direction is ipsilateral to pivot leg; Taylor, Dabnichki, & Strike, 2005). Among persons with LLA, compromised ankle function alters control of braking/propulsive and mediolateral forces during a turn (albeit along a circular vs. orthogonal path; Segal, Orendurff, Czerniecki, Shofer, & Klute, 2008; Ventura, Segal, Klute, & Neptune, 2011), thereby likely necessitating proximal adaptations of the trunk/pelvis to adequately redirect the body's center of mass. Furthermore, proximal compensations during turns may also exist to minimize discomfort within the residual limb-socket interface, particularly as it relates to torsion/shear (Heitzmann et al., 2015).

Inter-segmental coordination and momentum have been used for identification of compensational movement strategies during ambulation. For example, persons with unilateral LLA generate and arrest larger trunk and pelvic segmental momenta during walking (Gaffney, Murray, Christiansen, & Davidson, 2016), as well as alter segmental coordination strategies dependent on the presence of current LBP (Russell Esposito & Wilken, 2014). While recent efforts have similarly identified altered trunk-pelvic coordination strategies in able-bodied individuals (with and without LBP) executing turns (Smith & Kulig, 2016), there exist no studies specifically focused on trunk and pelvic compensations during turns among persons with LLA. Thus, the primary purpose of this study was to characterize proximal compensations using inter-segmental momenta and coordination during transient (90-degree) turns among persons with LLA. Although turns are predominantly associated with movement in the transverse plane, it was hypothesized that persons with vs. without LLA execute turns with altered trunk-pelvic segmental coordination, particularly in the sagittal and frontal planes, to overcome the aforementioned challenges associated with modulating braking/propulsive and mediolateral forces with altered ankle function. Secondarily, we hypothesized that such alterations in trunk-pelvic coordination would also be associated with larger ranges of segmental momenta among persons with vs. without LLA.

2. Methods

2.1. Participants

Eight persons with unilateral LLA of traumatic etiology (four with transtibial amputation [TTA], three with transfemoral amputation, and one with knee disarticulation [TFA]) and five persons without LLA (uninjured controls; CTRL) completed this study (Table 1). All participants provided informed consent approved by the Walter Reed National Military Medical Center Institutional Review Board. All participants were free of neurological and orthopaedic injury aside from lower limb amputation, were able to ambulate over even terrain without an assistive device, and were not experiencing any moderate or severe discomfort/pain, regardless of cause, at any point during data collection, as measured by overall pain scores less than 4 cm on a 10 cm Visual Analog Scale (Jensen, Chen, & Brugger, 2003). Of the persons with TTA, 2 wore the RUSH and 2 wore the Vari-Flex XC foot. Of the persons with TFA or knee disarticulation, 2 wore the X3 microprocessor knee and Vari-Flex XC foot, 1 wore the X2 microprocessor knee and Vari-Flex XC foot, and 1 wore the Total Knee 2100 mechanical knee and Vari-Flex XC foot.

Table 1
Demographic information by participant category (CTRL = uninjured controls, TTA = persons with transtibial amputation, and TFA = persons with transfemoral amputation or knee disarticulation). Note, there were no significant differences in demographic information or walking speeds (all $P > .167$).

	Age (yr)	Months Since Amputation	Height (m)	Mass (kg)	In-line Walking Speed (m/s)
CTRL	20		1.8	61.5	1.4
	28		1.7	88.4	1.4
	31		1.9	105.7	1.4
	28		1.9	72.6	1.3
	29		1.8	83.5	1.3
TTA	24	5.5	1.8	90.9	1.4
	27	47.8	1.8	106.9	1.4
	34	133.3	1.9	89.9	1.5
	45	17.7	1.8	135.6	1.5
TFA	34	59.7	1.7	71.4	1.1
	23	15.8	1.9	96.2	1.4
	26	59.0	1.7	74.9	1.4
	25	32.9	1.7	101.2	1.2