Clinical Biomechanics 30 (2015) 1119–1124

Contents lists available at ScienceDirect

Clinical Biomechanics

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

Changes to transtibial amputee gait with a weighted backpack on multiple surfaces☆

Sean S. Doyle [a,*], Edward D. Lemaire [b,d], Markus Besemann [c], Nancy L. Dudek [d]

[a] University of Ottawa, School of Human Kinetics, Canada
[b] Ottawa Hospital Research Institute, Centre for Rehabilitation Research and Development, Canada
[c] Canadian Forces Health Services, Canada
[d] University of Ottawa, Faculty of Medicine, Canada

ARTICLE INFO

Article history:
Received 29 September 2014
Accepted 25 August 2015

Keywords:
Gait
Amputees
Load-bearing
Uneven
Ramp

ABSTRACT

Background: Modern prosthetic technology and rehabilitation practices have enabled people with lower extremity amputations to participate in almost all occupations and physical activities. Carrying backpack loads can be an essential component for many of these jobs and activities; however, amputee gait with backpack loads is poorly understood. This knowledge gap must be addressed in order to further improve an individual's quality of living through changes in rehabilitation programs and prosthesis development.
Methods: Ten male, unilateral, K4-level (ability or potential for prosthetic ambulation that exceeds basic ambulation skills, exhibiting high impact, stress, or energy levels), transtibial amputees completed ten walking trials at a self-selected pace on simulated uneven ground, ramp ascent, and ramp descent. Five trials were with a 24.5 kg backpack load and five trials without. Temporal–spatial parameters and kinematic peak values for the ankle, knee, hip, pelvis, and trunk were collected and analyzed for differences between backpack conditions.
Findings: Each surface had novel findings not found on the other surfaces. However differences in temporal–spatial parameters were congruent with the literature on able bodied individuals. Pelvis and trunk angular velocities decreased with the backpack. Hip flexion on both limbs increased during weight acceptance while wearing the backpack, a common adaptation seen in able-bodied individuals on level ground.
Interpretation: A 24.5 kg backpack load can be accommodated by transtibial amputees at the K4 functional level. Future studies on load carriage and gait training programs should include incline and descent due to the increased difficulty. Rehabilitation programs should verify hip and knee flexor strength and work to reduce intact limb reliance.

1. Introduction

Modern prosthetic technology and rehabilitation practices have enabled people with lower extremity amputations to participate in a majority of occupations and physical activities. Carrying backpack loads is an essential component for some of these jobs and recreational activities; however, amputee gait with backpack loads is poorly understood. An understanding of prosthetic gait during load-carriage could be used to optimize rehabilitation and prosthetic strategies that improve mobility, enabling individuals with amputations to accomplished load-bearing tasks more easily and potentially reduce injury risk (Knapik et al., 1996; Ren et al., 2005). However, biomechanical research on backpack loaded gait is lacking for the amputee population.

A backpack load changes able-bodied gait by shortening step length (Kinoshita, 1985; Knapik et al., 1996; Martin & Nelson, 1986; Vacheron et al., 1999), increasing stride rate or cadence (Martin & Nelson, 1986; Vacheron et al., 1999), increasing double support time (Kinoshita, 1985; Knapik et al., 1996; Martin & Nelson, 1986; Xu et al., 2009), decreasing swing phase (Ghori & Luckwill, 1985; Knapik et al., 1996; Martin & Nelson, 1986), but not changing single stance time (Charteris, 1998; Martin & Nelson, 1986). Some common kinematic changes include, but are not limited to, increases in knee and ankle angles and knee range of motion (Attwells et al., 2006; Kinoshita, 1985). Hip flexion during weight acceptance and hip extension during push-off also increase when wearing a weighted backpack (Attwells et al., 2006). A backpack load also decreases pelvic and trunk rotation (LaFiandra et al., 2002, 2003; Martin & Nelson, 1986; Smith et al., 2006), decreases pelvic obliquity range of motion (Smith et al., 2006), and increases trunk flexion (Kinoshita, 1985; Singh & Koh, 2009).

☆ The study was performed at The Ottawa Hospital Rehabilitation Centre, Centre for Rehabilitation Research and Development.

* Corresponding author at: Centre for Rehabilitation Research and Development, 505 Smyth Road, Ottawa, ON, K1H8M2, Canada.
E-mail addresses: sean.s.doyle86@gmail.com (S.S. Doyle), elemaire@ottawahospital.on.ca (E.D. Lemaire), markus.besemann@forces.gc.ca (M. Besemann), ndudek@ottawahospital.on.ca (N.L. Dudek).

http://dx.doi.org/10.1016/j.clinbiomech.2015.08.015
0268-0033/© 2015 Published by Elsevier Ltd.

Load carriage gait studies have predominately been on level ground. Subsequently, knowledge gaps exist for backpack gait biomechanics on other surfaces, especially for the amputee population. It was hypothesized that, on inclines and uneven ground, a weighted backpack will produce increased double support time, decreased pelvic and trunk movement speeds and range of motion, increased knee and hip flexion during weight acceptance, and increased hip extension during push-off. This study explored temporal–spatial and kinematic gait responses to a backpack load when people with transtibial amputations walked on simulated uneven ground and ramps.

2. Methods

A convenience sample of ten male, unilateral, high functioning (K-level 4), traumatic transtibial amputees were recruited (average height = 1.76 ± 0.07 m, weight = 88.0 ± 18.4 kg, age = 35.9 ± 8.1 years, years since amputation = 5.7 ± 5.4). Participants had their prosthesis for at least one year, used their device on a daily basis, and had successfully completed a gait training program. Each participant provided informed consent and signed a consent form. The research protocol was approved by research ethics boards at The Ottawa Hospital and University of Ottawa. A prosthetist ensured that the prosthesis functioned appropriately and that the residual limb was healthy. Participant three had a worn prosthetic foot and inferior socket fit due to recent weight loss; however, he did not want to change his prosthesis so testing proceeded with his regular device.

All data collection occurred at The Ottawa Hospital Rehabilitation Centre's Rehabilitation Technology Lab (RTL). After participant characteristics were recorded, a 24.5 kg weighted backpack (Jaenen et al., 2010) was fitted to the person and they were given sufficient time to accommodate to the load. Subsequently, reflective markers were attached to the body according to a six degree of freedom marker set.

Participants completed five trials without the backpack (NP) and five trials with the backpack (WP), on three surfaces. Walking surface order was randomized for each person. Adequate rest was provided between trials. The procedure was:

- Simulated Uneven Ground: Walk at a self-selected pace along an 8 m walkway that was covered with medium density foam mats (maximum compression of approximately 8 cm) to simulate an uneven surface. Participants walked the entire 8 m walkway.
- Ramp Ascent: Walk at a self-selected pace up an 8 m ramp with a 7 degree incline. Handrails were located at the top of the platform.
- Ramp Descent: Walk at a self-selected pace down an 8 m ramp with a 7 degree incline.

Marker data were collected at 120 Hz using an eight camera Vicon Nexus system[1]. Visual 3D[2] was used to calculate lower extremity, pelvis, and trunk kinematics. Peak values were extracted from each trial, based on events defined by Winter & Sienko (1988). A complete list of analyzed event labels and descriptions is included in Table 1. Outcome values were averaged over the five trials for each task/condition.

The averaged values were compared between NP and WP conditions for each walking surface. Inter-subject outliers were removed using Tukey's hinges (Hoaglin et al., 1986), with a value of 3 times the interquartile difference to ensure that only extreme outliers were removed. After the assumption of normality was proved correct, paired t-tests ($p = 0.05$) were performed on the averaged values using SPSS. Since this is an exploratory study on an area with little or no previous biomechanical research, results are presented without a correction for multiple tests (Bonferroni, etc.) in order to provide necessary information on individual measure significance to aid future research. It should be noted that there were 201 t-tests performed over the course of the analysis, resulting in possibly an approximate 10 false positives.

3. Results

All statistical comparisons involved the WP and NP conditions. When the parameter was limb-specific, the WP and NP conditions were analyzed for intact and prosthetic sides.

3.1. Simulated uneven ground

For temporal–spatial analysis on simulated uneven ground, normalized walking speed (normalized to height) and overall stride length significantly decreased with the addition of a weighted backpack (Table 2). Intact limb step length, step time, and swing time were significantly less for WP. Prosthetic step length and swing time significantly decreased with the backpack. Double support time (DST) and intact limb steps/min significantly increased for WP.

The pelvis axial rotation range of motion (PR3), absolute maximum pelvis axial rotation angular velocity (PAV3), and absolute maximum trunk axial rotation angular velocity (TAV3) were significantly less for the WP condition (Table 3).

On the intact limb, maximum ankle plantarflexion angle during weight acceptance (AA1) was significantly less for WP (Table 4). Maximum knee flexion angle during intact limb weight acceptance (KA1), maximum knee flexion angular velocity during weight acceptance (KAV1), maximum knee flexion angular velocity during swing (KAV2), maximum hip flexion angle during weight acceptance (HA2), and maximum hip flexion angular velocity during weight acceptance (HAV2) were significantly greater for WP. Maximum knee extension angular velocity during swing (KAV3) and maximum hip extension angle during push-off significantly decreased for WP (HA1).

Table 1
Event labels and definitions.

Event label	Event definition
AA1	Maximum ankle plantarflexion angle during weight acceptance (°)
AA2	Maximum ankle dorsiflexion angle before push-off (°)
AA3	Maximum ankle plantarflexion angle during push-off (°)
AAV1	Maximum ankle dorsiflexion angular velocity after foot-flat (°/s)
AAV2	Maximum ankle dorisflexion angular velocity before push-off (°/s)
AAV3	Maximum ankle plantarflexion angular velocity during push-off (°/s)
KA1	Maximum knee flexion angle during weight acceptance (°)
KA2	Maximum knee extension angle during push-off (°)
KA3	Maximum knee flexion angle during swing (°)
KAV1	Maximum knee flexion angular velocity during weight acceptance (°/s)
KAV2	Maximum knee flexion angular velocity during swing (°/s)
KAV3	Maximum knee extension angular velocity during swing (°/s)
HA1	Maximum hip extension angle during push-off (°)
HA2	Maximum hip flexion angle during weight acceptance (°)
HA3	Maximum hip adduction angle during push-off (°)
HA4	Maximum hip abduction during swing (°)
HAV1	Maximum hip extension angular velocity during push-off (°/s)
HAV2	Maximum hip flexion angular velocity during weight acceptance (°/s)
HAV3	Maximum hip adduction angular velocity during push-off (°/s)
HAV4	Maximum hip abduction angular velocity during swing (°/s)
PR1	Pelvic tilt range of motion (°)
PR2	Pelvic obliquity range of motion (°)
PR3	Pelvic axial rotation range of motion (°)
TR1	Trunk flexion range of motion (°)
TR2	Trunk abduction/adduction range of motion (°)
TR3	Trunk axial rotation range of motion (°)
PAV1	Pelvic tilt angular velocity absolute maximum (°/s)
PAV2	Pelvic obliquity angular velocity absolute maximum (°/s)
PAV3	Pelvic axial rotation angular velocity absolute maximum (°/s)
TAV1	Trunk flexion angular velocity absolute maximum (°/s)
TAV2	Trunk abduction/adduction angular velocity absolute maximum (°/s)
TAV3	Trunk axial rotation angular velocity absolute maximum (°/s)

[1] Vicon Motion Analysis Corp., 5419 McConnell Avenue, Los Angeles, CA 90066, USA.
[2] C-Motion, Inc., 20030 Century Blvd, Suite 104A, Germantown, MD 20874, USA.