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Xu Xu
North Carolina State University

Simon M. Hsiang
North Carolina State University

Gary Mirka
Iowa State University, mirka@iastate.edu

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Xu Xu[a], Simon M. Hsiang[a,**] and Gary A. Mirka[b]

[a]The Ergonomics Laboratory, Edward P. Fitts Department of Industrial and Systems Engineering, North Carolina State University, Raleigh, NC 27695-7906, U.S.A.

[b]Department of Industrial and Manufacturing Systems Engineering, Iowa State University, Ames, IA 50011, U.S.A.

** Corresponding Author: Dr. Simon M. Hsiang
Department of Industrial and Systems Engineering
North Carolina State University
Raleigh, NC 27695-7906
U.S.A.
Phone: (919) 513 7208
Fax: (919) 515 5281
Email: smhsiang@ncsu.edu

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Abstract [Word count 248]

A suspended-load backpack is a device that is designed to capture the mechanical energy created as a suspended backpack load oscillates vertically on the back during gait. The objective of the current study was to evaluate the effect of a suspended-load backpack system on selected temporal and kinetics parameters describing gait. Nine male participants carried a suspended-load backpack as they walked on an instrumented treadmill with varied levels of load (no backpack, 22.5 kg, and 29.3 kg) and walking speed (1.16 m/s, 1.43 m/s, 1.70 m/s). As the participants performed this treadmill task, ground reaction forces were collected from an instrumented treadmill system. From these data, temporal variables (cycle time, single support time, and double support time) and kinetic variables (normalized weight acceptance force, normalized push off force, and normalized mid-stance force) were derived. The results showed that the response of the temporal variables were consistent with previous studies of conventional (i.e. stable load) backpacks. The response of the normalized push off force, however, showed that increasing walking speed significantly ($p<0.05$) decreased the magnitude of this force, a result contrary to the literature concerning conventional backpacks where this force has been show to significantly increase. Further evaluation revealed that this reduction in force was the result of a phase shift between the movement of the carried load and the movement of the torso. This suggests that the motion of the load in a suspended load backpack influences the gait biomechanics and should be considered as this technology advances.

Keywords: Suspended-load backpack, Ground reaction force

[Word count 1195 (Introduction – Discussion)]

1. Introduction

Rome et al. [1] describe a suspended load backpack system capable of generating electricity by harvesting the mechanical energy extracted from the motion of a suspended load relative to the torso during gait. Through the interaction between a toothed rack (mounted to the suspended load) and a pinion gear/geared dc motor system (mounted on the backpack frame), the system is capable of generating up to 7.4 watts of power that can be used to power a cell phone, a handheld GPS, or other portable electronic devices. While these authors showed only modest increases in metabolic demand with the suspended load (3.22% increase as compared to a fixed load), one potential obstacle to the adoption of this technology is the potential for this suspended load system to generate new and unusual inertial forces that could result in maladaptive gait patterns. The aim of the current study was to quantify the effects of a suspended-load backpack on several temporal and kinetic parameters of human gait.

2. Methods

2.1 Participants

Nine male participants were recruited from a university population. The participant group had a mean age of 26.3 (SD 1.5) years, height 177 (SD 4.2) cm, leg length 95 (SD 1.9) cm, and body mass 70.8 (SD 12.0) kg. The experimental protocol was approved by the NCSU Institutional Review Board for the Protection of Human Subjects in Research. A tenth subject was recruited but was not able to perform the task.

2.2 Apparatus

A military ALICE backpack was modified by adding a suspended aluminum plate between the original frame and the sack (Figure 1). The frame of the backpack system was secured to the torso through the shoulder and the hip belts. The sack is mounted on the aluminum plate which is suspended by four springs and free to move up and down through four Teflon bushings. The equivalent spring stiffness of this system was about 4000 N/m, while the equivalent damping coefficient was unknown. The mass of the system without any additional load was 6.7 kg.

Figure 1

During the walking trials, the ground reaction forces were captured by Gaitway Instrumented Treadmill (Model 685, Kistler Instrument Corp.) and recorded at the frequency of 100 Hz. Using these data the dependent variables describing the gait were derived as described in Section 2.4.

2.3 Independent variables

The independent variables in this study were load weight and walking speed. There were three levels of load weight: no backpack, 22.5 kg (15.8 kg oscillating load), and 29.3 kg (22.6 kg oscillating load). There were three levels of walking speed: 1.16 m/s, 1.43 m/s and 1.70 m/s. The levels of these independent variables were chosen based on the range of backpack loads and walking speeds seen in the literature [2, 3].

2.4 Dependent variables

The dependent measures chosen for this study were consistent with the temporal and kinetic variables investigated in previous studies of conventional backpacks [4, 5, 6]. The temporal variables were gait cycle time (CT), single support time (SST), and double support time (DST). The kinetic variables were normalized weight acceptance force (NWAF - defined as the peak force during the weight acceptance phase divided by whole body weight), normalized push off force (NPOF – defined as the peak force during the push-off phase divided by whole body weight), and normalized mid-stance force (NMSF – defined as the minimum force occurring between NWAF and NPOF divided by whole body weight).

2.5 Experiment Procedures

Upon arrival, the participants were provided with an introduction to the experiment and written informed consent was obtained. A five minute stretching and warm-up routine was followed by the gathering of some simple static anthropometric data including weight, stature, and leg length. A brief training was given with the treadmill to ensure that the participants could perform the required trials. During the experiment, the participants walked on the treadmill under each of the nine speed-load conditions (randomized order). Each condition was performed for 1.5 minutes and the last minute was monitored by the instrumented treadmill. A break of five minutes was provided between successive trials.

2.6 Data Analysis

The mean of all of the occurrences of each dependent variable in this one minute period of data collection was calculated, generating one observation per condition per subject. MANOVA was performed on the temporal variables and kinetic variables separately. Subsequent univariate ANOVA procedures were then performed to further clarify these significant effects ($p<0.05$).

3. Results

The MANOVA results indicated that load weight and walking speed were statistically significant for both the temporal and kinetic variables while the load weight*walking speed interaction was statistically significant only for the kinetic variables (Table 1). Subsequent univariate ANOVA and graphical analysis (Figure 2) showed that the responses of the temporal variables were generally consistent with the responses seen in previous research on convention (stable load) backpacks [5, 6]. As backpack load increases, time spent in single stance significantly decreases while the time spent in double stance significantly increases. Further, as walking speed increases, both single stance time and double stance time decrease, results also consistent with previous research. The results of the analysis of the normalized push off force, on the other hand, showed a significant decrease with increasing walking speed (NPOF section of Figure 2), a result inconsistent with that shown in previous research on conventional backpacks.

Figure 2 and Table 1
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4. Discussion

The results with regard to push-off force seen in the current study were not consistent with the findings of Hsiang and Chang [4] which showed that when a participant was wearing a conventional backpack, the push-off force significantly increased with increased walking speed. Based on the inverted pendulum model of human walking [7, 8], the center of gravity of a human reaches a minimum and the vertical ground reaction force reaches a maximum during double support phase. With a conventional backpack the movement of the fixed load in the backpack is roughly in-phase with the movement of the torso and the downward force exerted by the load also reaches the maximum during double support phase. For the suspended-load backpack, the friction associated with the spring-damper system introduces a phase shift between the movement of the carried load and the torso resulting in a lag between the movement of the torso and the movement of the load. This phase shift delays the maximum force transferred from the load to the torso [1], which then results in a decrease in the push-off force. This result supports Kuo's suggestion [9] that due to the phase delay of the load, the suspended-load backpack is able to reduce the energy cost of muscles during the transition from the single support to the double support. The results of this study suggest that the suspended load backpack system can impact the biomechanics of gait and these changes must be considered. Future research should focus on the sensitivity of the temporal and kinetic gait parameters to the characteristics of the task (backpack load, speed of movement (including running)), and anthropometry of user. These studies may provide insight into the appropriate values of spring constants and damping ratios that will allow the system to generate the needed power without significantly impacting gait performance.

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Table 1 MANOVA and ANOVA results of temporal and kinetic variables.

Temporal Variables

	MANOVA		CT		SST		DST	
	F	p	F	p	F	p	F	p
Load	31.98	<.0001	1.64	0.2017	8.93	0.0004	16.96	<.0001
Speed	71.54	<.0001	247.28	<.0001	42.19	<.0001	14.11	<.0001
Load*Speed	0.91	0.5596	-	-	-	-	-	-

Kinetic Variables

	MANOVA		NWAF		NPOF		NMSF	
	F	p	F	p	F	p	F	p
Load	128.37	<.0001	720.44	<.0001	147.32	<.0001	136.92	<.0001
Speed	48.92	<.0001	209.36	<.0001	18.99	<.0001	44.37	<.0001
Load*Speed	7.16	<.0001	7.2	0.0058	16	<.0001	5.88	0.0189

$p<0.05$ is considered significant

FIGURES

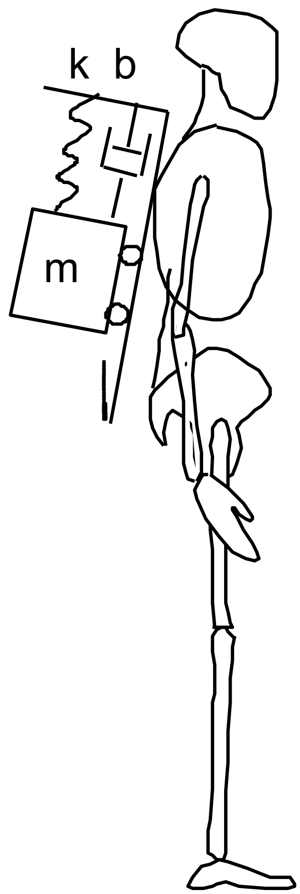

Figure 1. The suspended-load backpack.

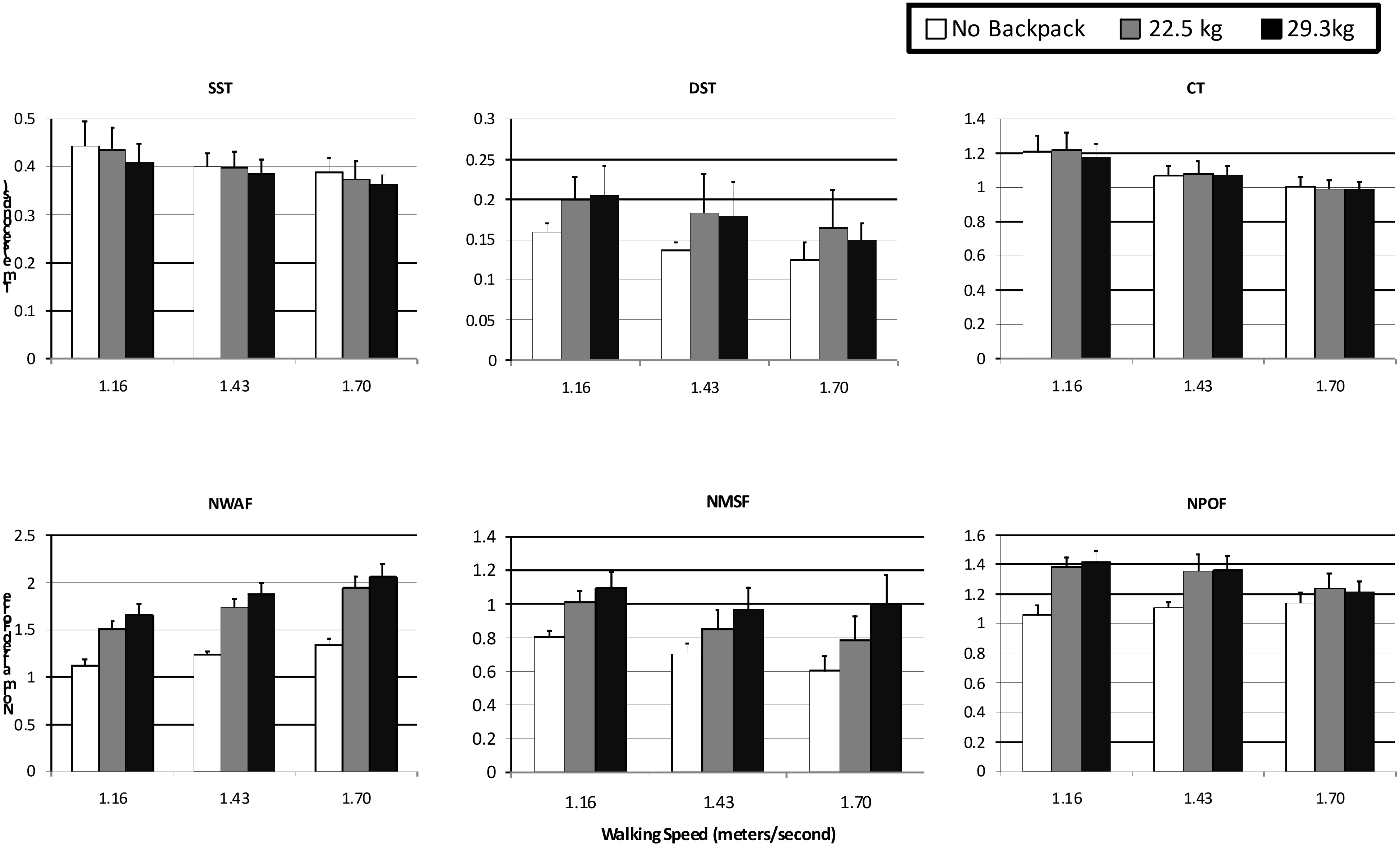

Figure 2. Effect of load and walking speed on the temporal and kinetic variables of human gait. (Error bars show one standard deviation.)