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Effects of cognitive and physical loads on local dynamic stability during gait

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ABSTRACT

The objective of this study was to examine the main and interactive effects of cognitive and physical loads on soldiers' gait characteristics. Twelve young healthy male participants volunteered to take part in the study. They were instructed to walk on the treadmill at their comfortable speed under different combinations of physical and cognitive loads. The physical load was applied by carrying backpack load that was set at 0 kg, 8.5 kg, and 20 kg, respectively. The cognitive task was to speak out the name of the months in a reverse order as accurately as possible, starting from any random month specified by the experimenter. Gait characteristics were assessed using local dynamic stability measures. Only physical load had significant effects on local dynamic stability. No interactive effects between cognitive and physical loads were found. The findings from this study can aid in better understanding gait characteristics of load-carrying soldiers. In addition, practical implications can also be derived from the results of this study. For instance, in order to prevent unnecessary fall accidents in military training and combat, measures should be taken to reduce the backpack load for soldiers.

1. Introduction

Soldiers often have to walk across long distances with back-carrying heavy load in military training and combat. Overload can directly result in high muscular tensions which could be associated with injury, muscle strain and joint problems. Knapik et al. (1996) reported that load carriage could result in a series of medical problems such as foot blisters, metatarsalgia, stress fractures, knee pain, low-back injuries, rucksack palsy, etc. Besides, load carriage in a military scenario can immediately adversely affect soldiers' mobility and thus compromise their battlefield performance. Due to these, it is important to have good knowledge on the effects of load carriage on soldiers' behaviors.

Physiological response to soldiers' load carriage has been examined (e.g. Beekley et al., 2007; Crowder et al., 2007; Fallowfield et al., 2012; Quesada et al., 2000). In a study by Quesada et al. (2000), for instance, male soldier participants were exposed to three backpack load conditions (i.e. 0%, 15%, and 30% body weight) during a simulated level road march on a treadmill. Various physiological measures including oxygen consumption, ventilation, and heart rate were found to be significantly different between loads throughout the marches. Crowder et al. (2007) studied the physiological demands of soldiers during a simulated graded road march. They examined two similar load levels (i.e. 29.1 kg vs. 26.3 kg), and three elevation grade levels (i.e. 0%, 5%, and 10%) using the physiological measures including oxygen uptake, carbon dioxide output, ventilation, respiratory exchange ratio, and heart rate. No significant differences were found in this study between the two load levels in each graded condition.

Knowledge of gait characteristics of load-carrying soldiers can help effectively assess soldiers' mobility especially during road marching. In addition, falls are a serious health problem among military personnel that led to an average hospital stay of 6.4 days (Senier et al., 2002), and gait analysis can help estimate the risk of falls among load-carrying soldiers. Therefore, besides physiological measures, many studies have also been done to investigate the effects of load carriage on gait kinematics and kinetics (e.g. Attwells et al., 2006; Beekley et al., 2007; Birrell and Haslam, 2010; Simpson et al., 2012). It was generally reported that heavy load carriage could result in increased hip joint range of motion (ROM), decreased knee ROM, increased trunk ROM, and increased gait variability (Attwells et al., 2006; Birrell and Haslam, 2009; LaFiandra et al., 2003; Smith et al., 2010; Qu and Yeo, 2011). A recent study (Birrell and Haslam, 2010) has suggested that evenly distributed load on the trunk could result in 10% reduction in the maximum braking force during gait.

Postural control during gait is cognitively (or attentionally) demanding. Effects of cognitive load on gait have been widely examined by using dual task paradigms (Dubost et al., 2006; Lajoie et al., 1993; Sparrow et al., 2002). In the dual task paradigms, gait is

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considered as the primary task, and gait parameters are measured and compared between with and without the presence of a secondary cognitive task (i.e. cognitive load). Soldiers often need to perform some cognitive tasks (e.g. talking and reasoning) concurrently with load-carriage in military activities. Based on these, it is of interest to study soldiers' gait when both physical load (e.g. backpack load) and cognitive load are applied simultaneously. However, to our knowledge, no investigation has been done to address this problem.

To fill this gap, we aimed to examine the combined effects of cognitive and physical loads on gait in the present study. We used local dynamic stability during gait to assess such effects. The measures of local dynamic stability were suggested to be indicators of fall risks (Lockhart and Liu, 2008), while falls are costly due to time lost from duty and medical care for loaded soldiers (Schiffman et al., 2006). We hypothesized that 1) both cognitive and physical loads would adversely affect local dynamic stability during gait and increase fall risks, and that 2) there would exist interactive effects between cognitive and physical loads on local dynamic stability during gait.

2. Methods

2.1. Participants

Twelve young healthy male participants (age: 25.6 ± 2.4 years; height: 1.72 ± 0.05 m; weight: 69.2 ± 11.2 kg) volunteered to take part in the study. The participants were randomly selected from Singaporean male population from the university and local community since healthy Singaporean males are required to serve as soldiers. All participants provided written informed consent which was approved by the local ethical committee, and self-reported to have no clinically conditions that may affect their gait patterns.

2.2. Experimental protocol

The participants were required to change into sleeveless shirt and shorts, and to wear sports shoes at the beginning of the experiment. A test was then conducted to determine the participants' comfortable walking speed. In this test, the participant was asked to walk on a treadmill (Biodex RTM 600, Shirley, NY, USA) at a relatively small initial speed. Then, the treadmill speed was increased by a small amount (i.e. 0.1 mph) on each successive trial until the participants reported that they felt uncomfortable with the speed. The treadmill speed was then increased further and slowly decreased by the same small amount on each successive trial until the speed was reported to be comfortable. The average of the transition speeds was taken as the comfortable speed.

During data collection, three reflective markers were placed on the sternum and two heels, respectively. The participants were instructed to walk on the treadmill at their comfortable speed under different combinations of physical and cognitive loads. An eight-camera motion capture system (Motion Analysis Eagle System, Santa Rosa, CA, USA) was used to collect reflective marker location data at the sampling rate of 100 Hz.

The physical load was applied by carrying backpack load (Fig. 1). Backpack load carriage is a common load transfer method especially in military and recreational activities (Schiffman et al., 2006). There were three physical load levels: no load, low load, and high load. The backpack load weighed 8.5 kg and 20 kg in the low load and high load conditions, respectively. The cognitive load was applied when performing a cognitive task in which the participants were instructed to speak out the name of the months in a reverse order as accurately as possible, starting from any random month specified by the experimenter. This cognitive task demands cognitive resource from the phonological loop. There were two cognitive load levels defined by the absence and presence of the cognitive task.

Fig. 1. Participants carrying backpack load during walking trials.

A factorial experimental design was adopted in the present study. Therefore, totally six testing conditions (3 physical load levels × 2 cognitive load levels) were examined in the experiment. One walking trial was conducted under each testing condition, and each walking trial last 3 min. After establishing a steady-state gait pattern, 110 consecutive walking strides were recorded from each walking trial for calculating dependent measures (i.e. local dynamic stability measures). Kang and Dingwell (2006) suggested that trial lengths of 2 and 3 min can ensure good reliability of local dynamic stability measures. The duration of the selected 110 consecutive walking strides in all the walking trials ranges from 125.4 s to 167.1 s. Between two consecutive trials, the participants were given an at least 2-min break in order to minimize carry-over effects and to avoid confounding effects caused by fatigue. In addition, to minimize order effects, the testing conditions were presented in a random order across the participants.

2.3. Dependent measures

Local dynamic stability, which is determined by the maximum finite-time Lyapunov exponent (λ_{max}), was used to assess gait characteristics. This nonlinear dynamics approach was reported able to quantify neuromuscular control processes related to the control of dynamic stability during gait and to account for falling mechanisms (Dingwell and Cusumano, 2000; Dingwell and Martin, 2006). When calculating local dynamic stability, an n-dimensional state-space X is constructed as:

$$X(t) = [x(t), x(t+T_D), x(t+2T_D), \ldots, x(t+(n-1)T_D)] \quad (1)$$

where $x(t)$ is the single dimension time series data, n is the embedding dimension, and T_D is a constant time delay. The maximum finite-time Lyapunov exponent for a dynamic system is determined from:

$$d(t) = d_0 e^{\lambda t} \quad (2)$$

where $d(t)$ is the average Euclidean distance between nearest neighbors at time t, and d_0 is the initial average separation between trajectories. Nearest neighbors are the data points from separate cycles that are closest to each other in state space $X(t)$. Taking the logarithm of both sides of Eq. (2) yields: