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Upper extremity hemodynamics and sensation with backpack loads

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ABSTRACT

Heavy backpacks are often used in extreme environments, for example by military during combat, therefore completion of tasks quickly and efficiently is of operational relevance. The purpose of this study was to quantify hemodynamic parameters (brachial artery Doppler and microvascular flow by photoplethysmography; tissue oxygenation by near-infrared spectroscopy; arterial oxygen saturation by pulse oximeter) and sensation in upper extremities and hands (Semmes-Weinstein monofilament test and 2-point discrimination test) while wearing a loaded backpack (12 kg) in healthy adults for 10 min. All values were compared to baseline before wearing a backpack. Moderate weight loaded backpack loads significantly decreased upper extremity sensation as well as all macrovascular and microvascular hemodynamic values. Decreased macrovascular and microvascular hemodynamics may produce neurological dysfunction and consequently, probably affect fine motor control of the hands.

1. Introduction

Backpacks are used by children and adults to carry objects over a long distance. Children often carry backpacks that exceed the recommended weight guidelines provided by several Medical and Health Societies (Rodriguez-Oviedo et al., 2012; Talbott et al., 2009; White et al., 2000). Over 92% of children in the United States carry backpacks which are typically loaded with 22% body weight (Negrini et al., 1999; Watson et al., 2002). In addition, adults in professions such as the military, firefighting, and mountain rescue routinely carry packs loaded with 60% body weight (Birrell et al., 2007; Rodriguez-Soto et al., 2013).

Previous studies of children demonstrate that backpack loads (10–30% body weight) significantly increase contact pressures beneath backpack shoulder straps (Macias et al., 2005, 2008). In fact, this backpack strap contact compression of underlying tissue is higher than the pressure thresholds (approximately 30 mm Hg) to occlude skin blood flow (Macias et al., 2008). Backpack straps often compress the anterior part of the shoulder, situated in the region over the brachial plexus, axillary artery and vein (Kolodinsky and Brandschwei, 1989; Makela et al., 2006). Therefore, if compression of these tissues occurs it may affect hand/arm circulation and sensation. One study found that a third of backpackers report transient upper extremity paresthesias (Boulware, 2003). In some occupational categories, upper extremity and hand function is required to perform work while donning a heavy backpack. Therefore, reduced sensation and blood perfusion in the hand could impair task function. Heavy backpacks are often used in extreme environments, for example by military during combat, therefore completion of tasks quickly and efficiently is of operational relevance. The purpose of this study was to quantify hemodynamic parameters (brachial artery flow, forearm muscle oxygenation; and microvascular flow, arterial oxygenation) and sensation in upper extremities and hands while wearing a loaded backpack in adults. We hypothesize that backpack loading decreases brachial artery flow, forearm muscle oxygenation; and microvascular flow, arterial oxygenation and sensation in the finger.

2. Materials and methods

All study protocols were approved by Institutional Review Board of the authors' institution. Our experimental design

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involved two components. First, measurements of brachial artery blood flow and microvascular flow at the index finger confirmed donning a backpack impacts hemodynamics. The second component of the study sought to determine tissue oxygenation at the volar forearm and index finger; followed by sensation tests (subjective paresthesia, Semmes-Weinstein (SW) monofilament, and 2-point discrimination tests). Inclusion criteria were normal healthy subjects without history of skeletal or vascular disease. Exclusion criteria were a history of cardiovascular, and/or circulatory pathologies. Specific exclusion criteria include: atherosclerosis, intermittent claudication, acute or chronic deep venous thrombosis, peripheral occlusive arterial disease, diabetes, and hyperparathyroidism. Pregnant women were also excluded as the hemodynamic responses may be different during pregnancy. Moreover, subjects with musculoskeletal injuries or orthopaedic disease in the upper limb, back or spine were not allowed to participate in this study (for example, all subjects with histories of carpal tunnel syndrome, herniated disc, shoulder surgery or injury and severe back pain with inability to stand up with backpack weight were excluded).

For the first part of the study, after written informed consent was obtained, 8 subjects (6 men, 2 women, age range: 18–30 years) underwent the right brachial artery measured with ultrasound Doppler. Brachial artery flow velocity measurements were assessed using color flow duplex imaging (HDI 5000, Philips Medical Systems, Bothell, WA, USA). A 7.75 MHz linear array probe held at a constant 60° angle of insonation measured brachial artery flow velocity medial to the biceps brachii muscle, midway between the antecubital and axillary regions. Time-averaged velocity (mm/s) and brachial artery cross-sectional area (measure in square mm) were calculated using Philips software, and brachial artery blood flow was calculated by multiplying the two. A single investigator performed all duplex measurements as well as analysis of all duplex data. Subjects were instructed to stand with their arms relaxed at their sides and baseline brachial artery flow velocity and brachial artery cross-sectional area were measured in the right arm. A conventional backpack (Model TYP7, Jansport, San Leandro, CA) without linking chest strap was loaded with 12 kg of books was then placed on the subject's shoulders in the standard 2-strap condition for 10 min. Strap length and position of the backpack was adjusted to comfortable levels for all volunteers. Brachial artery flow velocity and cross-sectional area measurements were repeated at the end of this 10-min backpack donning period. On a separate day, index finger pulp microvascular flow was measured using PPG (Mateus and Hargens, 2012). The device transmits light from a light emitting diode (LED) of two wavelengths (574 nm and 890 nm), which were then scattered in and absorbed by tissue. A small amount of light that was reflected was received by the probe photodetector. Variations in the detected signal related to blood flow and blood volume of the tissue of interest, such as skeletal muscle (Allen, 2007; Sandberg et al., 2005). Baseline flows were measured immediately before wearing loaded backpack after 2–3 min resting period for stabilization. Monitoring of PPG was performed during 10 min of 12 kg backpack wearing. For each subject, the PPG value obtained at the initial resting period was used as a reference value. All subsequent PPG data were normalized by dividing the reference value and multiplying by 100, thus giving an initial value of 100% for normalized data.

In second part of the experiment, 10 other subjects (7 men, 3 women, age range: 20–40 years) were recruited. The Type I error probability associated with this test of this null hypothesis is .05. For sensory measurement at the finger, patients were unable to observe the monofilaments touch their hand, the 10 g force Semmes-Weinstein (SW) pressure esthesiometer (Research Designs, Houston, TX) is used to conduct sensory tests on both index and little fingers (Collins et al., 2010; MacDermid et al., 1994). Two fingers were chosen in the hand, because they represent different nerve territories: index for the median nerve and little finger for the ulnar nerve. The SW monofilament was pressed perpendicular to the test site with enough pressure to bend the monofilament for 1 s. Subjects were asked to answer "Yes or No", when they felt or did not feel the press of the monofilament, respectively. If a subject did not perceive the filament at the site diameter, the filament was increased by one level and retested. The two-point discrimination test was executed in dynamic positions (Dellon et al., 1987). The two-point distance was increased by increments of .5 mm, which are measured with the digitized caliper (MAX-CAL, Japan Micrometer MFG Co., Osaka, Japan), until the subject felt the two compression points. Then resting arterial oxygen saturation was measured with PO (Nellcor N-200, Covidien-Nellcor, Boulder, CO) at the index finger of the subject and tissue oxygenation was monitored with NIRS device (INVOS Oximeter 5100, Somanetics Corp, Troy, MI) at the volar compartment of the forearm (proximal 1/3 of the forearm). NIRS of the volar forearm muscle was measured the balance between oxygen delivery and consumption (Boushel and Piantadosi, 2000; Celie et al., 2012). The NIRS device measured absorption of light transmitted from an LED through the muscle at two different wavelengths (760 and 850 nm). Using the ratio of the AC and DC components of the signals at the two different wavelengths, a change in oxygenation state of hemoglobin that are correlated with tissue oxygen saturation (Breit et al., 1997; Mohler et al., 1997). The measuring site for each test was decided with permuted block randomization technique among 10 subjects. Baseline data were collected after 2–3 min after reaching stable state. Once data were acquired, subjects wore the same 12 kg backpack for 10 min. Data were recorded and the sensory tests were repeated as same protocol and position as baseline. All the experiments were done in same condition at the room temperature (23 °C)

All statistical analyses were performed using the SPSS software package (version 17.0, SPSS Inc, Chicago, IL). Pre- and post-loading data were compared and analyzed with either paired t test or Wilcoxon sign rank test depending on the characteristic of the variable. Data are presented as means ± SD.

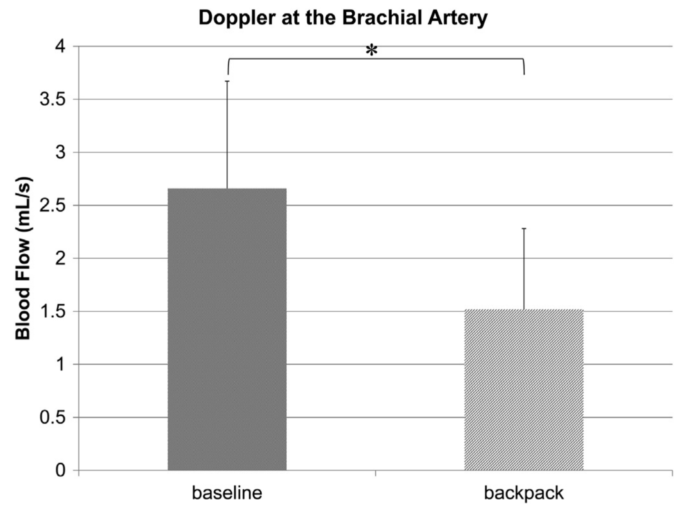

Fig. 1. Brachial artery blood flow (mL/s) at baseline (no backpack load) and after 10 min of wearing a 12 kg backpack. Blood flow decreased significantly compared to baseline ($p = 0.002$).