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Shoulder skin and muscle hemodynamics during backpack carriage

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ABSTRACT

The purpose of this study was to quantify the effects of loaded backpacks on shoulder muscle oxygenation, skin blood flow, and pain. We hypothesized that backpack load carriage is associated with lower shoulder muscle oxygenation and skin microvascular flow. Near-infrared spectroscopy quantified shoulder tissue oxygenation and laser Doppler flow measured skin microvascular flow. Eight adult volunteers donned a standard backpack without added load, 5 kg load, and 10 kg load for 5 min while standing. An 8 min rest period before each backpack donning condition ensured that all measured parameters returned to baseline. Data were analyzed using a repeated measures ANOVA and significance set at $p < 0.05$. Donning a 10 kg backpack significantly reduced shoulder muscle oxygenation by 22 ± 23% as compared to the empty backpack control condition ($p = 0.023$). In addition, a 10 kg backpack load reduced skin microvascular flow by 82 ± 22%, as compared to the empty backpack control condition ($p = 0.024$). Perceived pain was significantly higher when wearing the 10 kg backpack (level 4 on a 10-maximal pain scale) as compared to the empty backpack (0, 0–no pain) ($p < 0.05$). In conclusion, backpack loads of 10 kg decrease shoulder muscle oxygenation and skin microvascular flow.

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1. Introduction

Adults and children use backpacks for recreational and occupational purposes to transport items. In the United States, fourth and fifth grade students carry a mean backpack loads of 10% and 12% of their body weights, respectively (Forjuoh et al., 2003). In Italy, school children carry backpack loads with a median average load of 9.3 kg or 22% of their body weights (Negrini et al., 1999). In addition, typical backpack loads of Australian school children (age range 8–12 years) are 5.3 kg or 10% of their bodyweight on average (Grimmer and Williams, 2000). In a survey, with over 92% of the children typically carrying backpacks, muscle soreness is the most reported symptom (67.2%) (Pascoe et al., 1997). Specifically, in this same study 14.7% of children report shoulder pain when donning a backpack (Pascoe et al., 1997). Children carrying (age 6 years) 15–20% bodyweight backpack loads (average load range 3.4–4.6 kg) display muscle fatigue in the upper trapezius after 10 min and in the lower trapezius after 15 min (Hong et al., 2008). In another study with children, backpack loads weighing 10%–30% bodyweight significantly increase skin contact pressure beneath backpack straps and pain (Macias et al., 2005). In addition, Macias and co-workers observe asymmetric pressure distributions of the right and left shoulder during backpack carriage (10%, 20%, and 30% bodyweight loads) by school children (Macias et al., 2005). These observed shoulder skin contact pressures during backpack carriage are higher than the pressure thresholds to occlude local tissue blood flow (Macias et al., 2005).

Heavy backpack usage may also affect shoulder health in adult populations. For example, computer models of backpack carriage in adults, using open MRI scans, demonstrate that a 25 kg backpack compresses the tissues beneath backpack straps with an average contact pressures of 10 kPa on the trapezius (Hadid et al., 2012). The magnitude of these compressive forces beneath backpack straps are sufficient to induce nerve damage (Hadid et al., 2012). One study finds that compression from backpack loads displayed increased signs of muscle fatigue in the upper trapezius (Piscione and Gamet, 2006). Recent data by Kim et al. (2014), support these computer model predictions, documenting that a 12 kg backpack decreases tactical sensation at the fingers and lowers brachial artery blood flow.

However, it is unclear if shoulder tissue blood flow is compromised during backpack load carriage. Classic studies by Holloway and coworkers demonstrate that forearm skin blood flow decreases 65% with a 10 mmHg of externally applied pressure (Holloway et al.,

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1976). Therefore, we sought to determine if shoulder skin blood flow and muscle oxygenation are affected while donning a loaded backpack. In addition, we sought to determine if a reduction in hemodynamic parameters are related to perceived pain. We hypothesize that increasing backpack load decreases muscle oxygenation and skin blood flow in the shoulder, while causing increased shoulder pain.

2. Materials and methods

This study was approved by the University of California, San Diego Institutional Review Board. All volunteers were verbally informed of the study protocol and risks, volunteers read and signed consent forms prior to testing. Subjects that had any history of musculoskeletal disorders in their upper extremity and back were excluded and not enrolled in the study. Eight subjects (4 men, 4 women, age range: 21–34 years, mean weight ± SD: 64.8 ± 15.2 kg) were tested in the present study. The subjects all wore T-shirts. A Jansport® backpack (San Leandro, CA; 0.7 kg) was worn continuously throughout the experiment.

Tissue oxygenation and skin blood flow levels were measured noninvasively with near-infrared spectroscopy (NIRS) (Celie et al., 2012; Hampson and Piantadosi, 1988) and with laser Doppler flow (LDF) (Aratow et al., 1991; Hodges and Del Pozzi, 2014; Watenpaugh et al., 2004), respectively. Specifically, NIRS was used to measure tissue oxygenation in the forearm in a previous backpack study (Kim et al., 2014). To minimize signal interference the devices were placed on opposite shoulders. The NIRS sensor and the LDF probe were placed over the right and left upper trapezius muscles for all subjects, respectively. The sensor and probe were placed under the backpack strap beneath the T-shirts and against the skin (Fig. 1). Both the sensor and the probe were located proximally transverse to the disc between the first and second thoracic vertebra. Both devices sampled tissue areas where pressures from the backpack straps were applied. Placement of the NIRS sensor (7.5 cm by 3.8 cm; 2 mm thick) and LDF probe (8 mm diameter; 2.2 mm thick) in this orientation provide continuous muscle oxygenation and skin blood flow monitoring of the upper trapezius. The tissue oxygenation was measured with a NIRS device (INVOS 5100C, Somanetics Corporation, Troy, MI), which used light-emitting diodes (LED) to transmit light at wavelengths of 730 and 810 nm and monitored a penetration depth of about 1–2 cm. The sensor has two detectors spaced 3 cm and 4 cm from the LEDs. The LED photons travel in a parabolic path to the detector (Cui et al., 1991). The NIRS device calculates the difference of the shallow signal from the deep signal to give an oxygenation value deep in the tissue without superficial signal contamination. The NIRS data were reported in units of regional oxygen saturation (rSO_2). The LDF device (LASERFLO® Model BPM 403A, Vasamedics, Inc., Saint Paul, Minnesota) used a 780 nm laser diode and achieved a blood flow measurement depth of approximately 1 mm. LDF device is a Doppler based technique, measuring Doppler shifts of the back-scattered light due to the moving red blood cells (Nilsson et al., 1980). The LDF data were reported as voltage outputs. We express LDF measures as relative changes in blood flow from a baseline value.

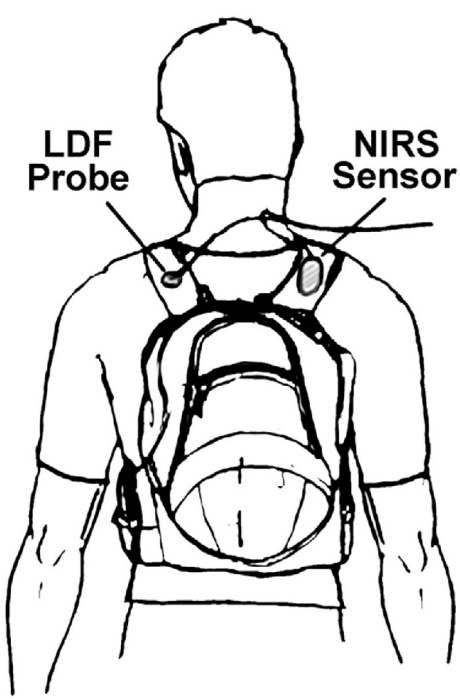

Fig. 1. The NIRS sensor and the LDF probe were placed over the right and left upper trapezius muscles, respectively. They were placed under the backpack strap beneath the subjects' T-shirts and proximally transverse to the disc between the first and second thoracic vertebra for all subjects. LDF probe and NIRS sensor not drawn to scale for graphically clarity.

The volunteers donned a backpack with three different conditions: empty, 5 kg load, and 10 kg load. To maximize surface contact area of the backpack and prevent load carriage of the backpack on the buttock, then backpack straps were adjusted so the backpacks were all worn with the top of the backpack at shoulder level throughout the experiment, for example, the backpack straps were adjusted to maximize the contact of the backpack with the volunteers' back (Fig. 2). In the beginning of the experiment, subjects donned an empty backpack sitting for 8 min. Sitting positions in the experiments were used solely to allow the volunteers' muscle oxygenation and skin blood flow to return to baseline before continuing on to the next testing condition. Relevant data presented were all collected from the standing positions. Next, subjects stood for 5 min wearing an empty backpack in order to establish baseline values. The subjects rested for 8 min again with an empty backpack kept on to allow muscle oxygenation and skin blood flow to return to normal. We were not able to immediately check if skin blood flow and muscle oxygenation values return to baseline, but pilot studies determined that the 8 min resting period was sufficient for these measures to return to baseline. Furthermore, test order (either 5 kg or 10 kg condition) after baseline condition were randomized with equal number of subjects. Subjects wore either a 5 kg or 10 kg loaded backpack for 5 min followed by an 8 min rest period and repeated. Measurements taken from the last 60 s of the conditions were analyzed. Subjects rated their perceived pain in their shoulder at the end of each measurement using a visual analog scale (0 = no pain and 10 = worst pain imaginable). All tests were conducted at room temperature (24 °C).

Statistical analyses were performed using IBM SPSS Statistics (version 21.0, IBM Corp., Armonk, NY). Oxygenation and skin blood flow data were analyzed using repeated-measures ANOVA followed by pairwise comparisons (Least Significant Difference). Perceived pain data was analyzed with Wilcoxon signed rank test. Oxygenation and skin blood flow data were presented as means ± SD. Perceived pain data was presented as medians ± SD. Significance was set at $p < 0.05$.

3. Results

Increasing backpack load to 5 kg, and then to 10 kg significantly decreased trapezius oxygenation (Fig. 3, $p < 0.01$, main effect for load). Mean oxygenation levels after wearing an empty backpack,

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