REDISTRIBUTION OF TORSO-BORNE LOAD MAY INCREASE HAMSTRING MUSCLE FATIGUE

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INTRODUCTION

Soldier load (e.g. body armor, equipment and rucksack) restricts mobility, alters bodily kinematics and can lead to pain or injury if worn for an extended period of time [1]. Back and shoulder pain, primarily due to torso-borne loads, are two commonly reported musculoskeletal complaints among military personnel [2]. Utilizing devices to redistribute these loads from the shoulders to the pelvic region could help address these issues. However, while load redistribution devices may reduce shoulder discomfort, their effect on the lower extremity during both level and inclined gait is unknown. Transferring the torso-borne load to the pelvis could alter lower extremity neuromuscular function during gait and potentially lead to more rapid muscle fatigue development. Therefore, the purpose of this study was to determine if redistribution of load from the shoulders to the pelvic region affects lower extremity muscle activity and fatigue.

METHODS

Eleven males (20.4 ± 2.54 years; 1.77 ± 0.04 m; 76.3 ± 5.85 kg) had lower limb surface electromyography (EMG) data (Delsys, Natick MA) recorded at 2400 Hz while walking at 1.34 $m \cdot s^{-1}$ on an instrumented treadmill (AMTI, Watertown MA) at both 0 and 9% grades. Participants wore 29.7 kg of torso-borne load which included a load distribution device (Fig. 1). The level of load redistribution, measured as a percentage of shoulder pressure offloading, was set by flexible pressure sensors on the shoulders. Each participant completed a 10 minute trial for three offloading conditions at each grade: 1) high (70-90%), 2) medium (40-60%), and 3) low (10-30%). Additionally, a no offloading control condition was recorded. The order of conditions was randomized for each participant. For each condition, dominate limb EMG data of the biceps femoris (BF), medial gastrocnemius (MG), tibialis anterior (TA) and vastus medialis (VM) were collected for 30 seconds at the 5 minute mark during each 10 minute trial. Volunteers were provided 10 minutes of rest between each offloading condition and a day of rest between each incline condition.

Figure 1- Load Distribution Device with Body Armor [3]

EMG signals were systematically post-processed with custom Matlab scripts (Mathworks, Natick MA) using the following steps: 1) detrend by removing the DC offset, 2) bandpass between 6 and 500 Hz using a 2^{nd}-order Butterworth filter, 3) rectify, 4) create a linear envelope using a time-centered moving root-mean-square (RMS) with a 100 millisecond window length, 5) set an activation threshold at two standard deviations above the mean of the resting muscle EMG signal, 6) determine muscle onset and offset timings by locating the intersections of the activation threshold and the RMS signal, 7) perform a spectral analysis on the raw EMG signal between each onset and offset timing, and 8) average each dependent variable for each muscle burst.

For analysis, subject-based means were calculated for RMS peak amplitude and burst duration. Additionally, median spectral frequency (f_{med}) and the log of the 5^{th} order spectral index of muscle fatigue ($logFI_{nsm5}$) were calculated using raw EMG signals. The log of the ratio between spectral moments of order -1 and order 5 defined $logFI_{nsm5}$:

$$\mathrm{logFI}_{\mathrm{nsm5}} = log_{10}\left(\frac{\int_{f_1}^{f_2} \mathrm{f}^{-1} \cdot PS(\mathrm{f}) \cdot \mathrm{df}}{\int_{f_1}^{f_2} \mathrm{f}^{5} \cdot PS(\mathrm{f}) \cdot \mathrm{df}}\right)$$

where PS(f) represented the EMG power-frequency spectrum as a function of frequency f, and f_1 and f_2 were the low and high cutoff frequencies of the bandpass filter. This spectral index is more sensitive than traditional indices (e.g. f_{med}) and is a reliable metric to assess muscle fatigue during dynamic contractions [4]. A repeated measures ANOVA tested the main effects and possible interactions between offloading condition and grade. Bonferroni pairwise comparisons were examined when statistically significant ($p<0.05$) differences were observed.

RESULTS AND DISCUSSION

Redistribution of load from the shoulders to the pelvic region increased BF peak amplitude (p=0.015) indicating that the redistribution likely increased BF muscle fiber recruitment. However, pairwise comparisons revealed that the 9% increase (4 mV; p=0.341) between the low and medium conditions and the 14% increase (6 mV; p=0.051) between the low and high conditions were not significant. Similarly, the increase in pelvic load caused an increase in BF $logFI_{nsm5}$ (p=0.044), representing a decrease in higher frequencies. However, pairwise comparisons showed that neither the 0.25% increase (0.033; p=1.00) between the low and medium offloading conditions, nor the 1.3% increase (0.166; p=0.310) between the low and high offloading conditions were significant. Since there was a main effect of offloading condition on BF amplitude and $logFI_{nsm5}$, the results suggest an amplitude increase and a shift to lower frequencies between the control and the high offloading condition. This increase in hip extensor activity may occur as a result of an increased hip flexion moment created by the altered load application.

While none of the remaining examined muscles were affected by load redistribution condition, the BF, VM and MG all experienced changes with respect to grade. There was an increase of peak amplitude in the BF (p<0.001), the VM (p=0.001) and the MG (p=0.001) at the 9% grade, indicating increased activity in the knee flexors, knee extensors and ankle plantar flexors. Specifically, participants exhibited a significant 58% (21 mV) increase in peak amplitude of the BF, a 178% (103 mV) increase of the VM and a 73% (78 mV) increase of the MG. To possibly further counteract the increased antagonist knee flexor activity, the burst duration of the VM also increased 17% (46 ms; p=0.01). Grade did not alter TA muscle activity, indicating that ankle dorsiflexor fatigue development during level and uphill walking was similar or did not occur. In addition to amplitude and burst duration increases with grade, f_{med} of the MG decreased 19% (18.51 Hz; p=0.016), yet similar decreases of f_{med} were not evident for the other examined muscles. However, the more sensitive $logFI_{nsm5}$ revealed a significant increase of 2% (p=0.014) in the MG and 3% (p=0.007) in the VM indicating a shift towards lower frequencies and indication of fatigue. Since the body center of mass must elevate during each step of uphill walking, the ankle extensors, including the MG, and knee extensors, including the VM, must function at higher intensities than during level gait to consistently propel the body upwards.

CONCLUSIONS

By redistributing Soldier load from the shoulders to the pelvic region, muscle firing patterns of the BF were altered, indicating an increase in peripheral muscle fatigue. This also suggests that the hamstrings may tire more at greater levels of shoulder offloading. The MG, TA and VM were not affected by the load redistribution device, but future research could focus on additional lower extremity muscles. The neuromuscular function of the hip and pelvic stabilizers may be of interest since the point of load application occurs lower on the torso. Elevating the treadmill grade increased muscle activity in the BF, MG and VM, and caused reduced high frequency content of the MG and VM indicating signs of fatigue. Implementation of neuromuscular training for targeted muscle groups could help reduce the likelihood and severity of fatigue symptoms. Specifically, focused training of the BF and other hamstring muscles may prove beneficial if load redistribution devices become standard issue in the military.

REFERENCES

1. Attwells RL, et al. Ergonom. 49(14),1527-1537
2. Cohen SP, et al. The Spine Journal. 12, 833-842
3. Source Tactical Gear. http://source-military.com/
4. Dimitrov GV, et al. J. of ACSM. 1971-1979