

Statistical Parameter Mapping Analysis of Trunk, Shoulder Girdle, and Shoulder Kinematic Alterations Associated with Body Armor

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1. Introduction

Body armor (BA) is an essential part of the protective equipment worn by warfighters and law enforcement personnel to mitigate the risk of penetrating trauma to the torso during tactical engagements. During upper extremity movements, wearing BA may prompt deviation from normal upper extremity and trunk kinematics due to the added mass over the shoulder girdle and trunk. In contrast to comparing discrete points during a task, statistical parameter mapping (SPM) provides for examination of differences across an entire movement trajectory (Pataky et al., 2015). Thus, the purpose of this investigation was to examine trunk, shoulder girdle, and shoulder kinematic alterations associated with BA during upper extremity elevation (UEE) and a functional lifting task using SPM.

2. Methods

2.1 Participants

Healthy physically active (Ozemek et al., 2026), military aged participants (range 18-37 yrs) performed two tasks while wearing BA and without BA. Participants had no history of shoulder injury or surgery and tested negative for subacromial impingement during screening.

2.2 Procedures

The BA used was a military-grade Improved Outer Tactical Vest with soft armor panels and two hard ceramic ballistic plates (front, back). Four sizes ranging

from 7kg (extra-small) to 9kg (large) ensured proper and comfortable fit between participants. For the first task ($n=40$, 21 males, 72.1 ± 21.2 kg, 1.67 ± 0.28 m), participants performed bilateral UEE in the scapular plane while holding a dumbbell (1.36kg for participants with mass <68 kg; 2.27kg for participants with mass ≥ 68 kg) (Kardouni et al., 2015). The second task ($n=35$, 20 males, 73.7 ± 21.4 kg, 1.67 ± 0.30 m) involved an ammunition can (12.5kg) lift (ACL) from the floor (Lenton et al., 2016) and placing it on a shelf set to clavicular height. Five repetitions of each task were completed. Trunk, scapular, and humeral, kinematics were measured using an electromagnetic (EM) tracking system (100 Hz) with receivers secured on the skin over the 7th cervical vertebra, humerus, and acromion process, duplicating the process that was validated with bone pins (Karduna et al., 2001). Digitization of bony landmarks and computation of trunk, scapular and humeral kinematics followed the International Society of Biomechanics recommendations (Wu et al., 2005).

2.3 Data reduction and statistical analysis

Following time-normalization (0-100% of the task) and ensemble averaging across the five repetitions, trunk extension and dominant limb scapular upward rotation, scapular posterior tilt, scapular internal rotation, clavicular elevation, clavicular protraction, and humeral elevation were compared with paired-sample SPM tests (2-tailed, $\alpha=.05$) using SPM1d version M.0.4.50 (Pataky et al., 2015).

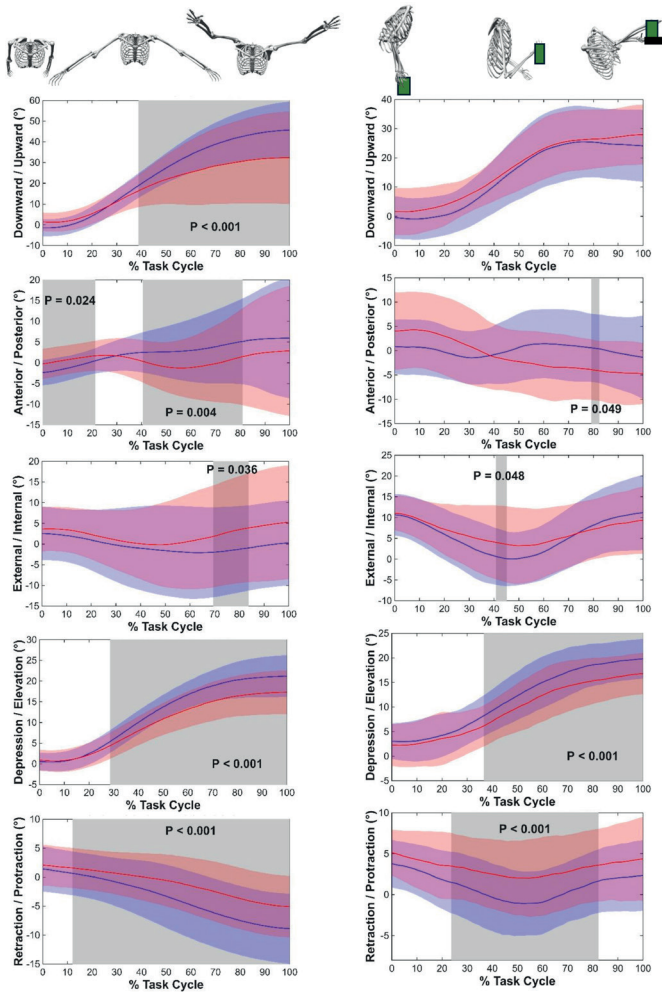


Figure 1. The results of statistical parameter mapping for scapular (upward rotation, posterior tilt and internal rotation) and clavicular (elevation and protraction) kinematics. Comparisons are shown between wearing body armor (red) and without body armor (blue) during upper extremity elevation (left panel) and ammunition can lifting (right panel). Gray shaded regions indicate a statistical difference between conditions ($P < 0.05$); shaded bands around the mean lines represent \pm one standard deviation.

3. Results and Discussion

The SPM analysis yielded several significant effects of BA during both tasks (Figure 1). During UEE, wearing BA resulted in a significant decrease in scapular upward rotation beginning mid-cycle through the end of the movement. Wearing BA elicited significantly greater scapular posterior tilt during the initial phase of the movement (0 to 18%), followed by a significant increase in anterior tilt mid-cycle (40 to 80%). In contrast, wearing BA did not significantly alter scapular upward rotation

during the ACL task and elicited significantly greater anterior scapular tilt only during a brief interval (79 to 82%). Wearing BA resulted in very short durations (UEE: 69 to 84%, ACL: 41 to 45%) of significantly greater scapular internal rotation during both tasks. These kinematic differences between tasks likely stem from the ACL task's heavier load and its movement pattern, which favored pure flexion over the broader humeral elevation seen in the UEE task. Wearing BA altered clavicular kinematics markedly in both the UEE and ACL tasks. After the initial third of the movement, clavicular elevation was significantly reduced for the remainder of both tasks while wearing BA. Furthermore, wearing BA induced significantly greater clavicular protraction throughout most of both tasks. The more pronounced impact of BA on clavicular kinematics, relative to the scapula, is likely due to the direct point of application of the armor over the clavicle. Wearing BA significantly increased HE during the onset of the UEE task (0–23%, $P = 0.002$), followed by a significant reduction during the terminal stage of the motion (59–100%, $P = 0.003$). In contrast to the UEE task, humeral elevation was statistically similar across the BA conditions during the ACL task. While BA application significantly increased trunk flexion during the mid-phase of the ACL task (38–52%, $P < 0.025$), it did not significantly affect trunk extension during the UEE task. The change in trunk flexion during the ACL task may serve as a compensatory strategy to stabilize the BA center of mass, minimizing trunk movement away from the base of support.

4. Conclusions

Wearing body armor resulted in significantly altered trunk, shoulder girdle and shoulder kinematics, though the magnitude and timing of the effects are task dependent. Across the two tasks, the most consistent finding was marked alteration of clavicular elevation and protraction. These findings suggest that evaluating protective gear requires a comprehensive evaluation of the entire shoulder complex. Future studies should evaluate experienced tactical operators to determine if these kinematic shifts increase injury risk and whether muscle strength serves as a protective factor against the effects of BA.

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Conflict of Interest Statement

None.

Contributor Roles

BLR: Conceptualization, Supervision, Methodology, Formal analysis, Software, Visualization, Writing original draft; SJ: Methodology, Data collection, Writing – review & editing, Project administration; ENW: Methodology, Data collection, Writing – review & editing, Project administration; JRK: Conceptualization, Supervision, Methodology, Writing – review & editing, Project administration.

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Data, software, code availability

SPM1d version M.0.4.50 (<https://www.spm1d.org>).

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