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Shoulder elevation affects joint position sense and muscle activation differently in upright and supine body orientations

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ABSTRACT

Objective: Investigate the effects of shoulder elevation on repositioning errors in upright and supine body orientations, and examine these effects on anterior and posterior deltoid muscle activation. We hypothesized decreased errors, and altered anterior and posterior deltoid activation with increasing elevation, in both orientations.
Design: Crossover trial.
Setting: University laboratory.
Participants: Thirty-five college-aged participants.
Intervention: Subjects attempted to replicate target positions of various elevation angles in upright and supine body orientations. Also, anterior and posterior deltoid activation was recorded in each shoulder position and body orientation.
Main outcome measures: Vector and variable repositioning errors, anterior and posterior deltoid percentage of maximal contraction.
Results: Vector error was greater in supine compared to upright at 90° and 110°, but not at 70°. Variable error was larger in supine than upright, but was unaffected by elevation. Anterior deltoid activation increased with elevation in the upright posture only. Posterior deltoid activation increased with elevation across postures.
Conclusions: Muscle activation, external torque, and cutaneous sensations may combine to provide afferent feedback, and be used with centrally-generated signals to interpret the state of the limb during movement. Clinicians may prescribe open kinetic chain exercises in the upright posture with the shoulder elevated approximately 90–100°.

1. Introduction

Joint stability is a critical factor in producing coordinated performance of functional movements in both activities of daily living and more dynamic athletic skills. It is the result of factors such as bony congruity, capsuloligamentous integrity, and afferent signals arising from joint and musculotendinous mechanoreceptors integrated within the central nervous system (CNS). These afferent signals are integrated within the CNS in a process termed proprioception (Sherrington, 1906). The description of proprioception has evolved through the years to include a combination of joint position sense (JPS), the ability of a person to identify the position of a limb in space, kinesthesia, the ability to detect limb movement (Aydin, Yildiz, Yanmis, Yildiz, & Kalyon, 2001), as well as the senses of muscular tension and effort (Gooey, Bradfield, Talbot, Morgan, & Proske, 2000; Proske & Gandevia, 2009). Additionally, several authors have proposed the contribution of the motor command to

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the appreciation of joint position and movement senses (Gandevia, Smith, Crawford, Proske, & Taylor, 2006; Smith, Crawford, Proske, Taylor, & Gandevia, 2009; Walsh, Gandevia, & Taylor, 2010). JPS is an important contributor to the maintenance of muscle stiffness and coordination about a joint and the production of smooth movements for optimal task performance and minimal injury risk (Madhavan & Shields, 2005; Sainburg, Poizner, & Ghez, 1993). It is especially important for the function of the shoulder, where stability is sacrificed for a large range of motion (ROM) (Janwantanakul, Magarey, Jones, & Dansie, 2001).

The mechanisms contributing to JPS have historically been explored in a variety of ways. Position matching paradigms involve one joint (usually the elbow) being passively taken to a predetermined position and active matching being attempted with the homologous joint of the contralateral limb. In these studies, authors have reported greater matching error magnitude and variability in conditions of unilateral muscle fatigue or external load, regardless of whether the fatigue or external load were affecting the reference or indicator limb (Gooey et al., 2000; Walsh, Hesse, Morgan, & Proske, 2004; Winter, Allen, & Proske, 2005; Worringham & Stelmach, 1985). Based on these findings, these authors proposed that cues regarding limb position are provided via muscle spindle activation and signals indicating gravitational forces on the arm, including Golgi tendon organs (GTOs) and the centrally generated sense of effort (Gooey et al., 2000).

More recent studies employing more unconstrained testing paradigms have pointed toward a combination of mechanisms contributing to position sense. Suprak, Osternig, van Donkelaar, and Karduna (2006) found that shoulder JPS improved as the elevation angle approached 90°, a finding they attributed to the importance of external joint torque modulating muscle activation and, therefore, muscle spindle sensitivity. This assertion was supported in a follow-up study by the same group, in which they found that shoulder JPS improved with the addition of external load at the wrist, while keeping the shoulder position constant (Suprak, Osternig, van Donkelaar, & Karduna, 2007). In a parallel study, Chapman, Suprak, and Karduna (2009) attempted to further delineate the roles of external joint torque and joint position on shoulder JPS by examining the effects of shoulder elevation on JPS acuity in both upright and 45° tilted torso postures. They reported that, when upper extremity positions were matched based on their orientation to the gravitational field, but characterized by different shoulder joint angles, repositioning errors were significantly different. They also reported no differences in JPS acuity when upper extremity positions were matched based on the position of the humerus with respect to the thorax, but differing in external joint torque. The authors interpreted these findings to indicate that humans may use some internal coordinate system to locate the limb in space. Also, given that the size of this effect was greater than that of the external load (Suprak et al., 2007), they posited that this reliance on an internal coordinate system may play at least as great a role as the external torque and muscle activation levels in locating the limb in space during movement. This contention was supported by previous work by Darling and Miller, who reported that subjects replicated arm positions with respect to the trunk with more accuracy than arm positions with respect to gravity, and concluded that perhaps some intrinsic coordinate system exists that the brain can integrate when visual cues are absent (Darling & Miller, 1995).

Taking this evidence together, it appears likely that humans incorporate multiple mechanisms, including both external joint torque (and resulting muscle activation) and some intrinsic coordinate system based on muscle length, joint receptor activation, and skin deformation in order to create an overall representation of the state of the limb. However, it is still unknown how relative weighting of these signals, especially the external torque and the joint angle, is decided on during movement and location of the limb. Perhaps if JPS acuity could be observed under conditions of identical joint angles, but joint torques could be altered, and even reversed, more insight could be gained regarding the relative importance of these characteristics to movement decisions.

Therefore, the purpose of the present study was to examine the effects of body orientation (upright vs. supine) and shoulder elevation angle (70° vs. 90° vs. 110°) on JPS acuity and variability. A secondary purpose was to examine the effects of body orientation (upright vs. supine) and shoulder elevation angle (70° vs. 90° vs. 110°) on muscle activation levels of the anterior and posterior deltoid muscles. This study expanded on the findings of Chapman et al. (2009) by employing a more exaggerated tilt condition so that the external torque at 90° of elevation would be minimized in the supine position, and reversed at 110°. Additionally, muscle activation measures in each condition were made to lend further insight into the relative role of muscle activation and musculotendinous mechanoreceptor contributions to JPS acuity. We hypothesized, in accordance with the findings of Chapman et al. and Suprak et al. (2006), that repositioning acuity and variability would improve with increasing shoulder elevation angle, and this effect would be similar in both the upright and supine postures. In addition, we hypothesized that, as a result of changing external torque, activation of the anterior deltoid would be highest at 90° in the upright orientation, but would decrease with elevation in supine, and that posterior deltoid activation would increase with elevation angle in supine.

2. Methods

2.1. Ethical approval

All procedures followed in this study and described in this paper were reviewed and approved by the Western Washington University Institutional Review Board for the ethical treatment of human subjects, in accordance with the latest revision of the Declaration of Helsinki. Prior to participation, all subjects read and signed an informed consent form, approved by the same review board.