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# The influence of cycle time on shoulder fatigue responses for a fixed total overhead workload

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ABSTRACT

The relationship between overhead work and musculoskeletal health depends on multiple task and individual factors. Knowledge gaps persist, despite examination of many of these factors individually and in combination. This investigation targeted task variation, as parameterized by cycle time within a fixed overall workload. Participants performed an intermittent overhead pressing task with four different cycle time conditions while overall workload and duty cycle was held constant. Several manifestations of fatigue were monitored during task performance. Endurance time was influenced by cycle time with shorter cycle times having endurance times up to 25% higher than longer cycle times. Surface electromyography (sEMG) results were mixed, with two muscles demonstrating amplitude increases (middle deltoid and upper trapezius) that varied with cycle time. sEMG frequency was not influenced by cycle time for any muscle monitored, despite decreases for several cycle times. Trends existed for the influence of cycle time on time-varying reported discomfort ($p=0.056$) and static strength ($p=0.055$); large effect sizes were present ($\eta_p^2=0.31$ and 0.27, respectively). The equivocal association of fatigue indicators and cycle time is analogous to the influence of other factors implicated in overhead work musculoskeletal risk, and probabilistic modeling offers a compelling avenue for integration of the known variation in the many factors that combine to inform this risk.



## 1. Introduction

Shoulder injuries are prohibitively expensive and intimately linked to overhead work. Lost time claims involving the shoulder are classified as “high impact” due to their repercussions for both workers and employers, and substantial contributions to long term disability costs that exceed $1.5 billion annually in Ontario (WSIB, 2013a,b). While the average lost time claim is approximately $30,000 CAD, the total cost to employers likely exceeds this estimate by a factor of five via indirect costs (WSIB, 2013a). The Bureau of Labor Statistics indicated that shoulder injuries account for 13.6% of musculoskeletal injury claims across all occupations (BLS, 2013), and generally require the greatest median number of days away from work. Overhead work, classified as working with the arms above shoulder height ($>90°$ of humeral elevation), is strongly associated with the development of pain and injury (Bernard, 1997; Grieve and Dickerson, 2008; van Rijn et al., 2010). Jobs requiring overhead work have two- to three-fold increases in risk for shoulder disorders, and have more shoulder–neck pain and discomfort (Bjelle, 1989; Miranda et al., 2005; Punnett et al., 2000; Wiker et al., 1989). Further, injury severity has been linked to cumulative exposure levels, with more tissue damage concomitant with increased exposure to overhead working postures (Svendsen et al., 2004).

Muscular fatigue dominates occupational shoulder injury mechanisms, particularly in overhead positions. Upper extremity muscle fatigue demonstrably alters healthy or typical glenohumeral and scapulothoracic kinematic relationships (Borstad et al., 2009; Chen et al., 1999; Chopp et al., 2010a, Chopp et al., 2011; Cote et al., 2009; Ebaugh et al., 2006; McQuade et al., 1998; Michener et al., 2003; Royer et al., 2009; Teyhen et al., 2008; Tsai et al., 2003). Specifically, superior translation of the humeral head, which reduces the subacromial space and has been identified in patients with subacromial impingement syndrome (SAIS) (Deutsch et al., 1996), can follow targeted upper extremity muscle fatigue, particularly of the rotator cuff (Chen et al., 1999; Chopp et al., 2010a; Cote et al., 2009; Royer et al., 2009; Teyhen et al., 2008; Tsai et al., 2003). Conversely, scapular reorientation, achieved by exhausting the periscapular stabilizing muscles, does not appear to have the same reducing effects on the subacromial

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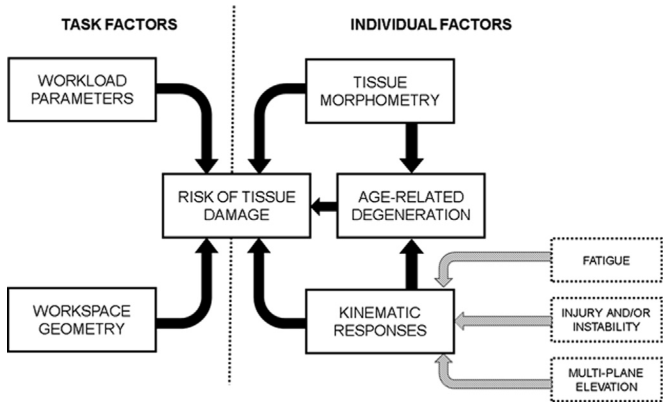


**Fig. 1.** A proposed conceptual representation of the multifactorial nature of musculoskeletal risk associated with overhead work. Past research efforts have alternately focused on aspects of each of the primary components and all areas are prone to large interpersonal or between/within task variability. The current study focuses on the influence of a workload parameter, namely cycle time, and its influence on indicators of potential shoulder injury risk, contributing to the overall understanding of occupational overhead work injury pathways.

space (Chopp et al., 2011; Ebaugh et al., 2006). Despite this finding, fatigue-induced glenohumeral and scapulothoracic kinematic alterations pose risk for shoulder instability and/or tissue damage, particularly to the distal supraspinatus tendon.

Numerous sources of variability potentially influence the distribution of musculoskeletal risk during overhead work within a population (Fig. 1). Firstly, interpersonal morphometric differences produce highly variable responses. Specifically, muscle attachment sites, body segment parameters, tissue dimensions and bone shapes vary widely in humans (Dickerson et al. 2011). A probabilistic analysis of altering the origin and insertion locations of upper and lower extremity muscles calculated differences in normalized predicted force magnitudes up to 51% (Chopp-Hurley et al., 2014) and moment arm length differences up to 41.3 mm (Pal et al., 2007), between 1% and 99% confidence intervals, respectively. Similarly, differences in body segment parameters and anatomical landmark uncertainty has resulted in a spectrum of force and moment predictions, with differences between 1% and 99% confidence limits as high as 53.6 N and 8.9 Nm, respectively for lower-extremity intersegmental forces and moments (Langenderfer et al., 2008). Experimentally, soft tissue and bone shape measurements vary considerably across a population. Reported subacromial tissue thickness measurements differ markedly, with magnitudes ranging from 2.5 to 7 mm and occupying between 50% and 75% of the subacromial space in healthy individuals (Cholewinski et al., 2008; Girometti et al., 2006; Joensen et al., 2009; Leong et al., 2012; Michener et al., 2013; Wang et al., 2005). Humeral and scapular morphological features implicated in SAIS and/or rotator cuff tears range substantially even in a healthy population, with acromial characteristic angles (acromial slope, acromial and tilt, lateral acromial angle, acromion index) angles differing substantially (Balke et al., 2013; Bigliani et al., 1986; Nyffeler et al., 2006; Tetreault et al., 2004). The combination of these interpersonal variabilities suggests highly individualized musculoskeletal injury risk from identical workplace exposures.

Different physical exposures powerfully influence physical outcomes across several dimensions. These dimensions include muscular fatigue responses and a corresponding divergence of kinematic responses. Specific directions and magnitudes of applied hand forces during overhead tasks differentially influence maximal force production, muscle loading, and performance and fatigue metrics. Hand forces in the vertical plane (lift/press) are associated with higher manual strength than in the horizontal plane (Haslegrave et al., 1997). For submaximal static forces, pushing backwards elicited the highest muscular demand compared to all other vertical and horizontal pushes (Chopp et al., 2010b). Perceived pain, muscular fatigue, and endurance time consequent to performing arm intensive tasks were sensitive to duty cycle and cycle times, but total work demand was not held constant (Garg et al., 2006; Iridiastadi and Nussbaum, 2006). Differential responses to various types of work exposures can result in highly variable fatigue outcomes. Specifically, glenohumeral and scapulothoracic kinematic responses to upper extremity fatigue have considerable interpersonal variability in the population (Chopp and Dickerson, 2012; Dickerson et al., 2011). Superior humeral head translation and three-dimensional scapular orientation following fatigue are reported to have widely differing magnitudes and polarities both across and within studies (Borstad et al., 2009; Chen et al., 1999; Chopp et al., 2010a, 2011; Cote et al., 2009; Ebaugh et al., 2006; McQuade et al., 1998; Teyhen et al., 2008; Tsai et al., 2003). As both mechanisms alter the size of the subacromial space (Chopp and Dickerson, 2012), this range of responses subsequently produces differential SAIS risk across the population, which is largely overlooked in occupational task assessment.

Resolution on how specific overhead work parameters influence responses including muscular fatigue development remains elusive, with important persistent gaps in knowledge. Previous research on intermittent overhead work has investigated multiple hand force levels, duty cycle or cycle time and their interactions with each other and shoulder muscle fatigue (Iridiastadi and Nussbaum, 2006; Mathiassen, 1993). However, modifying the presentation of a constant overhead task workload has not been evaluated. This study therefore examined the dependency of endurance time, static strength, and perceived discomfort on cycle time for a constant total workload, and determined how altering cycle time for the same overall workload modulated localized muscular fatigue development. It was hypothesized that shorter cycle times would provide more effective muscular recovery within a workload block, reducing indicators of fatigue for each measured outcome.

## 2. Methods

Ten university aged (21.6 ± 1.9 yr; 65.6 ± 11.3 kg; and 163.4 cm ± 7.1 cm), right-handed females with no self-reported shoulder injury within the past year participated. Females were selected due to the relative paucity of performance and fatigue data for females. Even in cases where exposures were normalized to strength, females used higher (approximately 5–10% MVC) proportions of muscular capacity (Chow, 2009), and thus may be more susceptible to shoulder fatigue. The study was approved by the institutional Office of Research Ethics.

In a training session prior to the collection date, each participant provided informed consent and had measurements taken. Anthropometric measurements consisted of participant height, weight, and hand, upper arm, forearm, and torso length. Three isometric static strength trials were completed in an overhead posture (identical to Task B below) with a minimum of two minutes rest between trials (Chaffin, 1975; Mathiassen et al., 1995). Participants performed a static strength exertion by producing a maximal forward push force with a power grip with an upright torso and both feet flat on the ground. Verbal encouragement was provided to elicit maximal effort (McNair et al., 1996). Static strength within an exertion was defined as the mean force during the middle three seconds of the five second contraction. The largest value of static strength from the three exertions performed by each participant was considered the maximum static strength.