Resolving the influence of work sequencing which includes overhead work: implications for job cycle designs

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

Many industrial workplaces involve tasks that require work to be performed in overhead postures. Epidemiological evidence suggests that working in these unavoidable, awkward postures leads to development of shoulder fatigue, pain and several musculoskeletal disorders. The accumulation of localized muscle fatigue has been strongly associated with the development of work-related musculoskeletal injuries (Armstrong et al., 1993). In order to prevent injury, minimizing muscular fatigue during short-cycled, repetitive work through different work organization schemes has been suggested (Dempsey et al., 2010). Previous research has examined the interactive effect of altering contraction level, duty cycle and cycle times on shoulder muscle fatigue. However, isolation of one factor while maintaining a constant workload has not been examined for overhead work tasks. The purpose of the study was to determine whether cycle time affected the progression of fatigue at the shoulder since the postural load during overhead tasks is inherently fatiguing.

Ten university aged females performed a task rotation between an intermittent overhead pressing task and a neutrally located assembly task. Four conditions were defined by cycle time (15s, 30s, 60s and 120s) and each cycle consisted of one complete rotation. In order to quantify the progression of fatigue over time, four dependant measures were systematically collected for all conditions until exhaustion or to a maximum of three hours. These included root mean square (RMS) amplitude and median power frequency (MdPF) calculated from surface electromyography of nine muscles surrounding the shoulder, static strength capability, and rating of perceived exertion. Endurance time was also included as a fifth measure of fatigue. Linear regression was used to determine the slope of static strength and perceived exertion over time, and magnitude changes over normalized time were calculated for EMG measures. For all dependant measures, repeated measures ANOVA were used to identify significant differences across conditions.

As the only independent factor investigated, cycle time influenced two out of the five dependent measures. Conditions induced differences in endurance time ($F[3,24]=3.96$, $p=0.02$) and RMS amplitude of the middle ($F[24,189]=3.10$, $p<0.0001$) and posterior deltoid ($F[24,189]=2.52$, $p=0.0003$). Performing overhead work in long cycles (120s) induced a shorter average endurance time (118.67min), and the shortest cycle time (15s) resulted in a longer average endurance time (152.44min). Over time, the rate of increase in RMS amplitude of both deltoid muscles was higher when working at the longest cycle time (120s). Although six muscles showed an indication of fatigue through significant decreases in MdPF in at least one condition, cycle time did not affect MdPF over time for any muscle examined. Similarly, the rate of static strength capability and rating of perceived exertion over time were not affected by cycle time.

Two of five measures indicated that cycle time played a significant role in fatigue progression, making its effectiveness as a work organizational method for overhead work tasks unclear. Results indicate that that intermittent overhead work should be performed in shorter cycles to reduce the risk of shoulder injury. Identifying additional effects of cycle time on fatigue measures through increasing statistical power would provide ergonomists with more confidence in recommending this organizational strategy to mitigate the risk of musculoskeletal injury.

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1.0 Introduction

1.1 Prevalence of work-related musculoskeletal disorders

Work-related musculoskeletal disorders are a common cause of occupational disability. In Ontario, 42% of all lost-time claims are due to musculoskeletal injuries (WSIB Statistical Supplement, 2009). In the US, a total of 3.1 million non-fatal workplace injuries and illnesses were reported in 2010 (Bureau of Labour Statistics, 2011). Of all industry sectors, manufacturing was the only one to experience an increase in incidence rate of injury from 4.3 cases per 100 workers in 2009 to 4.4 cases per 100 workers (Bureau of Labour Statistics, 2011). These high injury rates are detrimental to the productivity of a company and account for a substantial amount of government spending (Silverstein et al., 1998). Also, industries requiring repetitive work, put employees at a high risk of developing non-traumatic soft tissue musculoskeletal disorders (Silverstein et al., 2002). Frost and colleagues (2002) found an increased prevalence of shoulder tendinitis in workers performing highly repetitive tasks compared to matched referents. Reviews of the literature have identified risk factors associated with shoulder pain; these include performing repetitive movements, high load requirements and awkward postures (Sommerich et al, 1993; van der Windt et al., 2000).

1.2 Performing work "overhead"

Examination of jobs requiring elevated arm postures gives insight into the effects of muscle fatigue. Overhead work is defined as a task requiring an elevated arm posture to position the hand above acromial height (Bjelle et al., 1981). Working in overhead postures requiring an extended reach results in the generation of high external moments about the glenohumeral joint (Anton et al., 2001). The continuous activation of muscles involved in the maintenance of an elevated upper arm posture is required to counteract the external moments produced. Therefore, maintaining these elevated postures while completing overhead tasks results in earlier signs of shoulder muscle fatigue through EMG measures (Kadefors et al., 1976; Sigholm et al., 1984) and shorter endurance times (Nussbaum et al., 2001; Garg et al., 2002) compared to neutrally located tasks (Bjorksten and Jonsson, 1977). Since maintaining a prolonged, static overhead posture is fatiguing in itself, the majority of industrial jobs requiring overhead work are intermittent in nature (Bjorksten and Jonsson, 1977).

Through epidemiological research, overhead work has been directly linked to specific upper extremity musculoskeletal disorders. High odds ratios have been identified for rotator cuff tendinitis in occupations involving tasks at or above shoulder height (Hagberg and Wegman, 1987; Svendsen et al., 2004). Also, a systematic review revealed that working in overhead postures and repetitive movements of the shoulder were associated with subacromial impingement syndrome (van Rijn et al., 2010), a known predecessor to rotator cuff pathology.

1.3 Designing overhead work to prevent musculoskeletal injury

Several models of musculoskeletal injury have been based around the effects of local muscle fatigue. In 1991, Hagg introduced the “Cinderella” hypothesis which proposed that a small proportion of slow twitch muscle fibres continuously remain activated unless the muscle is completely relaxed. Performing tasks at a low load levels for prolonged periods of time will fatigue these “Cinderella units” and lead to injury of the muscle fibres (Hagg, 1991). The differential fatigue theory proposed by Kumar (2001) states that repetitive, uneven loading of muscles surrounding a joint may result in different rates of onset of fatigue. Over time, alteration in muscle loading to compensate for fatigued muscles may change the kinematics of the joint resulting in unnatural movement that may lead to injury (Kumar, 2001). These theories support the use of measures of local muscle fatigue in cross-sectional research to indicate potential development of musculoskeletal injury. Experimental and interventional research is required in order to effectively design jobs to reduce the amount of shoulder muscle fatigue when overhead tasks are involved.

Although performing work in an overhead posture has been identified to increase the risk of developing several musculoskeletal disorders, ergonomic guidelines for designing intermittent overhead work are scarce (Garg and Kapellusch, 2009). A NIOSH review recommended that shoulder postures with arm elevations greater than 60° from the horizontal be avoided due to strong association with rotator cuff tendinitis and pain (Bernard, 1997). Unfortunately, some work environments cannot be altered to remove work located overhead. When postural load cannot be changed, implementation of work organizational methods, such as rest allowances, job enlargement, job rotation and task sequencing should be evaluated in order to decrease the risk of injury. A review of the biomechanical and physiological mechanisms involved in repetitive work concluded that short cycles of intermittent work decrease the risk of developing shoulder fatigue (Kilbom, 1994). Previous studies of intermittent arm elevations have investigated multiple levels of external force, duty cycle and cycle time and their interactive effects on shoulder muscle fatigue (ex. Mathiassen, 1993; Iridiastadi and Nussbaum, 2006b). However, isolation of one factor while maintaining a constant workload has not been examined for overhead work tasks. Identifying individual factors contributing to fatigue development would provide insight into job design interventions effective in preventing musculoskeletal injury. The novelty of the current study lies within the isolation of the effect of cycle time on fatigue development during an intermittent overhead work task. Also, this study included an industrially relevant overhead posture, and task rotation instead of a work-rest schedule.

1.4 Purposes

The purposes of the study were:

- To evaluate the dependency of endurance time for an overhead task on cycle time at a constant workload, and
- To determine whether altering overhead cycle time while maintaining a constant workload changed the rate of localized muscle fatigue development.

1.5 Hypotheses

Considering the theory that short cycle times reduce fatigue accumulation over time (Kilbom, 1994), the first hypothesis was that endurance times would be longer for shorter cycle times of overhead work.

The second hypothesis stated that conditions of work involving shorter cycle times were predicted to delay the progression of localized muscle fatigue in the shoulder region. This was evaluated through four fatigue measures over time. It was hypothesized that shorter cycle times of overhead work would result in a:

- smaller rate of increase in rating of perceived exertion over time,
- smaller rate of decrease in static strength capability over time,
- smaller increase in EMG amplitude over time, and
- smaller decrease in EMG spectral measures over time.

2.0 Literature Review

2.1 Shoulder injuries in the workplace

Shoulder injuries have been prevalent in a variety of workplaces across North America. In 2008, the shoulder was the second most injured body part within the United States accounting for 13.8% of all work related musculoskeletal disorders (Bureau of Labour Statistics, 2009). In Ontario, approximately 4,300 lost-time claims were due to shoulder disorders alone resulting in 6.6% of all musculoskeletal disorders for the year (WSIB Statistical Supplement, 2009). Not only is the amount of these injuries substantial, but it appears that over time these values are not decreasing. In Washington State, incidence rates through compensation claims for upper extremity, non-traumatic soft tissue musculoskeletal disorders, such as rotator cuff syndrome, has remained unchanged over a period of eight years (Silverstein et al., 2002).

2.2 Shoulder anatomy and mechanics

The bony geometry and kinematics of the joints forming the shoulder complex allow for a relatively large amount of postural flexibility amongst the body joints. The shoulder complex includes three synovial joints: the glenohumeral, acromioclavicular, and sternoclavicular joints. The scapulothoracic articulation, although not considered a classically defined joint, helps guide the gliding movement of the scapula with respect to the torso. Rotations about all four articulations allow the shoulder girdle to have a relatively large range of motion in comparison to other joints of the body. During upper arm movements, the clavicle, scapula, and thorax act as a closed chain mechanism to determine placement of the humeral head (Veeger and van der Helm, 2007). The majority of thoracohumeral movement occurs at the glenohumeral joint, and the scapulathoracic articulation is responsible for the remaining motion. For abduction specifically, approximately 2/3 of the movement occurs about the glenohumeral joint, while scapular movement contributes to 1/3 of abduction (Codman, 1934).

Since the large range of motion of the glenohumeral joint compromises its intrinsic stability, stabilization is achieved through passive and active mechanisms. Passive mechanisms contributing to joint stability include: increased joint contact area and suction via the labrum, intra-articular pressure within the joint capsule, articular conformity between the humeral head and glenoid, ligament contributions at end range of motion, and joint proprioception (Schiffern et al., 2002; Veeger and van der Helm, 2007). Active stabilization is achieved through the coordinated activation of muscles crossing the glenohumeral joint (Kronberg, 1990; Wuelker et al., 1998). Muscles within the shoulder complex (Figure 1) are designed to attain a balance between maintaining sufficient force to stabilize the joint as well as complete tasks requiring use of the upper extremity.

Control of upper arm elevation is achieved through systematic activation of a series of muscles within the shoulder girdle (Wuelker et al., 1998). For example, arm abduction in the scapular plane requires activation of primarily four muscles: upper fibres of the trapezius elevate the lateral angle of the scapula (Wiedenbauer and Mortensen, 1952), the anterior and middle portion of the deltoid abducts the glenohumeral joint while elevating the scapula (Shevlin et al., 1969), and supraspinatus assists the middle deltoid throughout the range of abduction (Howell et al., 1986) but is primarily involved in joint compression (Wuelker et al., 1994). The size of shoulder muscles are relatively small compared to other joints, but have large moment arms which increases mechanical advantage (Kuechle et al., 1997). Also, during upper arm elevation, moment arms of certain muscles change in polarity which assists in stabilizing the humeral head within the glenoid (Kuechle et al., 1997). However, sustained postural loads created by elevated arm postures are sufficient to over-exert shoulder muscles, resulting in muscular fatigue, especially when applying hand forces or handling tools.

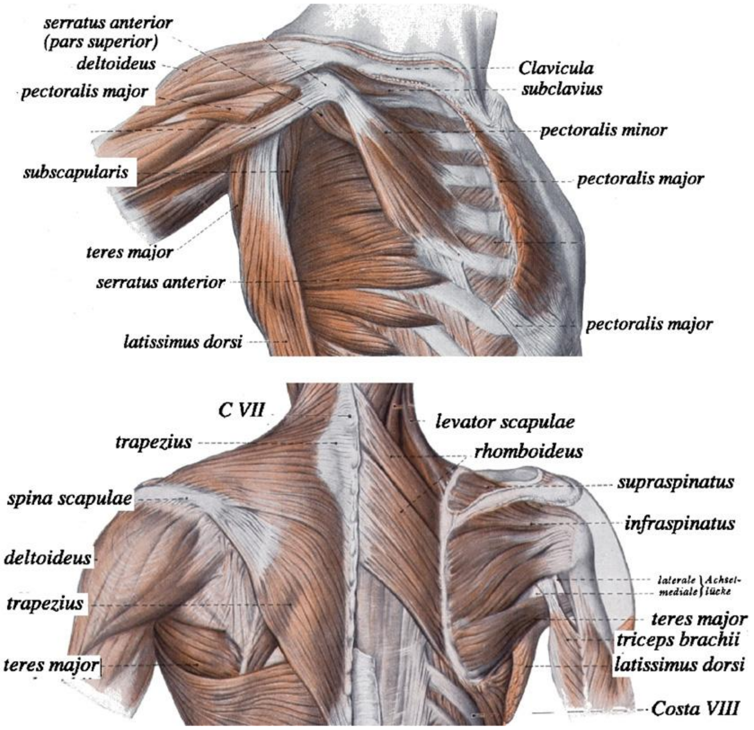


Figure 1: Muscles of the shoulder girdle (adapted from Benninghoff-Goertler (1964) Lehrbuch der Anatomie des Menschen, 9th edition, Urban & Schwarzenberg, Berlin)

2.3 Overhead work

Many working environments in the manufacturing, skilled trades, and construction industries cannot be modified to avoid overhead postures. This is problematic since several shoulder musculoskeletal disorders have been associated with performing overhead work. Through experimental research, possible biomechanical risk factors contributing to the development of these disorders have been investigated. Identifying these specific factors assists in the development of recommendations for designing overhead work tasks to decrease the risk of injury.

2.3.1 Associated musculoskeletal disorders

Many epidemiological studies have found strong associations between working overhead and the development of shoulder musculoskeletal disorders such as subacromial impingement syndrome, rotator cuff tendinitis, AC joint degeneration and bicipital tendinitis. An odds ratio of 11 was found for supraspinatus tendinitis in industrial workers working above shoulder height compared to those working below shoulder height (Hagberg and Wegman, 1987). More recently, in 2004, Svendsen and colleagues conducted a magnetic resonance imaging study and discovered an association between supraspinatus tenopathy and occupations involving work with the arm elevated over 90°. Compared to healthy manual workers, workers with shoulder pain persisting for longer than 3 months were found to have higher workloads at the shoulder (Bjelle et al., 1979). Finally, Miranda and colleagues (2005) conducted a population study on the determinants of chronic rotator cuff tendinitis using information from the Health 2000 survey in Finland. The most significant work-related factor in predicting the risk for developing rotator cuff tendinitis among both men and women was working with the hand above shoulder height.

2.3.2 Biomechanical risk factors

Although the association between overhead work and musculoskeletal disorders is apparent, the exact pathophysiology leading to musculoskeletal injury is unclear.

Accumulation of fatigue in muscles has been a widely accepted theory in the development of non-traumatic musculoskeletal injury (Armstrong et al., 1993). Many risk factors contributing to increases in joint loading, muscle activation and fatigue have been identified through cross-sectional, experimental research. In most studies investigating muscle load and/or fatigue during overhead work, the common muscles of interest are the upper trapezius, anterior deltoid, middle deltoid, infraspinatus and supraspinatus (Kadefors et al., 1976; Sigholm et al., 1984; Wiker et al., 1989).

Many studies have found upper arm elevation to be the most influential factor for inducing shoulder pain, muscle fatigue and injury in overhead work tasks (Herberts and Kadefors, 1976; Herberts et al., 1980; Bjelle et al., 1981; Wiker et al., 1990). A study replicating automotive assembly found that ratings of shoulder fatigue and pain increased with postures greater than 90° shoulder flexion and 120° elbow included angle (Garg et al., 2006). Also, overhead postures are a limiting factor in maximal force production. Isometric shoulder strength for females was significantly lower for exertions performed in overhead postures compared to postures with low degrees of shoulder flexion (Garg et al., 2005).

The vertical height of the working location also has been found to affect shoulder muscle load. Increasing the height of an overhead task results in an increased amount of shoulder muscle activity (Anton et al., 2001; Nussbaum et al., 2001). Conversely, studies altering the vertical height of overhead tasks were unable to detect significant changes in local muscle fatigue through EMG measures (Wiker et al., 1989; Sood et al., 2007). This could be attributed to the overhead task being too light, since detection of fatigue using EMG measures has been found to be unreliable for exertions less than 10-30% MVC (Hagberg and

Ericson, 1982; Chaffin and Anderson, 1984). Also, stature-scaling for overhead work height reduced muscle activity compared to a fixed work height (Chopp et al., 2010).

Horizontal reach distances have been found to increase the activity of certain shoulder muscles. Overhead work performed at a 0° target angle (directly overhead) reduced shoulder moment and decreased activation in the anterior deltoid and biceps muscles compared to horizontal reach distances in front of the body (Anton et al., 2001). However, this does not take into consideration visual impairments of the task and their effect on neck extension compromising practicality of the recommendations. Haslegrave and colleagues (1997) found that reach distances had a small, yet significant effect on maximum force production; the rearward location (target angle of -15° from a vertical directed through right shoulder) produced significantly lower values compared to 15° forward and 15° to either side. Chopp and colleagues (2010) also found that significantly higher activations were required to achieve the sub-maximal hand force for target angles of -15° and 0° compared to other locations.

The direction and magnitude of applied hand force during an overhead task influences production of maximal force and muscle loading. Maximum strength capability in overhead working postures is affected largely by the direction of force exerted. Specifically, hand forces in the vertical plane (lift/press) resulted in the highest forces compared to maximum forces developed in the horizontal plane (Haslegrave et al., 1997). Similarly, for sub-maximal static forces, pushing backwards elicited the highest amount of muscle activity, while pushing downwards required the least amount of total activation (Chopp et al., 2010).

Increased weight of hand tools in overhead tasks also significantly affects muscle activity and fatigue in shoulder muscles (Wiker et al., 1989; Garg et al., 2006).

The organization of overhead work through duty cycle and cycle time has been found to significantly increase risk of injury. In an observational study conducted by Punnett and colleagues (2000), it was found that automotive assembly workers who spent more than 10% of the cycle working in a severely flexed/abducted posture had the highest risk of developing a shoulder musculoskeletal disorder. A study simulating lifting and lowering a tool from neutral to overhead height examined duty cycles of 50% (2s/2s and 3s/3s) and 63% (3s/5s) (Garg et al., 2006). Out of the three combinations of arm up and arm down times, the most fatiguing task was the shorter cycle lengths (2s/2s) at 50% duty cycle (Garg et al., 2006). For an intermittent overhead tapping task, reduction in maximal force for a 67% duty cycle occurred an average of 62 minutes sooner than a 33% duty cycle (Nussbaum et al., 2001).

The amount of precision required to complete a task has been shown to effect shoulder muscle fatigue. Sporrong and colleagues (1998) reported an average increase of 22% in shoulder muscle activity when performing manual precision work. Specifically in welders, the fine motor control required in welding overhead fatigues more muscles in inexperienced workers compared to only the supraspinatus in experienced workers (Kadefors et al., 1976).

2.4 Work organization

Changes in work organization are targeted towards jobs requiring monotonous, repetitive work cycles throughout the day (Kilbom, 1994). These types of jobs have been associated with an increased risk of developing upper extremity musculoskeletal disorders (Bernard, 1997; Buckle and Devereux, 1999). Today, industrial jobs are becoming more short-cycled and monotonous which increases the importance of research to evaluate the physical benefits of work organization interventions (Mathiassen, 2006).

In order to decrease high levels of exposure to a potentially fatiguing task, different work organization techniques have been proposed and implemented into workplaces (Jorgensen et al., 2005). Theoretically, these interventions act as methods of physical exposure variation and aim to reduce overall muscular load during a workday in order to prevent muscle fatigue (Konz, 1998). Variation has been defined as the change in exposure across time, and can be implemented in a variety of ways (Winkel and Westgaard, 1992). Passive rest, such as adding rest breaks or micropauses, is used to decrease the amount of exposure over the work day (Rohmert 1973a; Bjorksten and Jonsson, 1977). Active rest, used in job rotation and job enlargement, targets the use of different muscle groups and/or different levels of exposure. These interventions are most effective when the tasks involved are physically diverse (Mathiassen, 2006). Although this concept seems logical, there have been inconsistencies within the experimental and interventional research to whether organizational changes are effective in protecting against musculoskeletal disorders (Winkel and Westgaard, 1992).

2.4.1 Rest breaks

Various rest allowance models have been created to determine the amount of rest breaks necessary to prevent muscular fatigue over a work day. In 1973, Rohmert proposed utilizing an equation involving maximal static force, endurance time, recovery time, and loading time for determining the amount of rest breaks required using the endurance limit curve. El ahrache and Imbeau (2009) compared rest allowances calculated from four models and discovered inconsistencies which were a result of the variables included in the models and differences in sample populations. A few studies have investigated psychophysically acceptable work-rest frequencies for lifting (Genaidy and Al-Rayes, 1993) and gripping tasks (Dahalan and Fernandez, 1993). However, most job designs of repetitive tasks are based on the Methods-Time Measurement (MTM) system, and do not allow employees to self-select the pace of work (Sundelin and Hagberg, 1992).

Conclusive evidence on the effectiveness of rest breaks through experimental research is lacking. Studies have shown that adding very brief rest breaks decreased the rate of fatigue accumulation (Mathiassen, 1993; Sundelin, 1993). However, Mathiassen and Winkel (1996) found that during repetitive light assembly tasks, added rest breaks did not have an effect on upper trapezius EMG amplitude over the work day. Also, multiple studies have reported no differences in ratings of perceived exertion for tasks with increased rest periods (Sundelin, 1993; Mathiassen and Winkel, 1996).

2.4.2 Job enlargement and job rotation

For jobs involving highly repetitive tasks, job enlargement strives to induce physical and mental variability by adding more tasks within a work day. In order for job enlargement to have a beneficial effect on mechanical exposure, variability between postures and muscle activity across the different jobs is necessary (Moller et al., 2004). Job enlargement using three electronic assembly tasks increased the between cycle variance in posture and upper trapezius activity compared to completing only one task (Moller et al., 2004). However, there have been inconsistencies to whether this organizational intervention is effective. In a field study on Danish hospital cleaners, it was found that variation through job enlargement did not provide enough physical variation, but improvement in mental health was seen (Sogarrd et al., 2006). Physical variation may not be observed because tasks within the work day are too similar. Similarity can be quantified through differences in muscle activity measured via electromyography (ex. Wells et al., 2010). As previously mentioned, job enlargement also has an effect on mental workload. Campion and McClelland (1991) found that enlarged jobs resulted in higher rankings of employee satisfaction, higher probability of finding errors, and less mental under-load.

Job rotation involves alternating between tasks in order to reduce high levels of loading over a work day (Jonsson, 1988). The tasks within a rotation scheme are required to recruit different muscle groups in order to have a preventative effect on fatigue (Raina and Dickerson, 2009). Few studies report on the effectiveness of this intervention in minimizing fatigue and injury risk. Hinnen and colleagues (1992) found that supermarket employees had less musculoskeletal complaints after implementing a rotation scheme between seated cashier work and other departmental work compared to only cashier work. Kuijer and colleagues (2004) implemented job rotation schemes for refuse truck drivers and collectors and found that this intervention decreased the workload compared to collecting alone, and increased the workload compared to driving alone. Effectiveness of job rotation is dependent on the tasks involved in the rotation. Having a high risk or high load job within a rotation may be ineffective since it exposes all of the workers, therefore increasing the risk of injury (Frazer et al., 2003).

2.4.3 Task sequencing

In manufacturing industries, work sequencing is commonly used as an intervention to increase productivity, but has recently been investigated to determine its effectiveness as a work organizational method. For example, assessment of work sequencing in paced automotive assembly lines has been conducted to increase the efficiency of work completed within a cycle (Yano and Rachamadugu, 1991). Since the primary goal of these interventions is to increase production, the effect it has on physical workload over time is not considered (Wells et al., 2007). From an ergonomic perspective, Dempsey and colleagues (2010) have expressed the potential benefits of self-selected temporal work organization on the worker, but more research is required to develop recommendations. If the order of task completion is irrelevant, changing the cycle time may induce a pattern of physical variation beneficial in decreasing fatigue accumulation over time. Several studies have examined different levels of duty cycles and cycle times to determine their effect on localized muscle fatigue using multiple physiological and subjective measures (Bystrom and Kilbom, 1990; Mathiassen, 1993; Iridiastadi and Nussbaum, 2006b).

2.5 Localized muscle fatigue

Since muscle fatigue has been associated as a potential precursor to musculoskeletal injury (Edwards et al., 1977; Vollestad and Sejersted, 1988), it is an important factor to consider for evaluating overhead work tasks. In 1984, Bigland-Ritchie and Woods defined fatigue as “any exercise-induced reduction in the ability to exert muscle force or power, regardless of whether or not the task can be sustained.” Also, fatigue is a time-dependant process and signs of muscular fatigue are evident before any decrement in force output (DeLuca, 1984).

Chaffin (1973) introduced the term ‘local’ muscle fatigue as “motor decrement and pain confined to the muscle”. In protocols involving intermittent sub-maximal contractions, fatigue was found to be due to local mechanisms since the neural drive to motor units remained constant (Bigland-Ritchie et al., 1986). Since many overhead work tasks are short-cycled and intermittent, evaluation of muscle fatigue at the local level was completed through multiple measures.

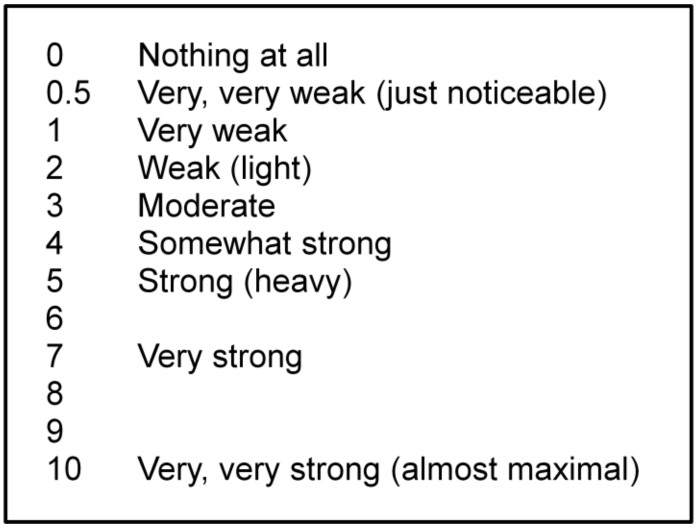
2.6 Assessment of fatigue

2.6.1 Surface electromyography (sEMG)

Surface electromyography gives insight into the neurological drive supplied to motor units. The sEMG signal consists of the sum of motor unit action potentials within the pickup zone of the electrode. Alterations in the EMG signal due to localized muscle fatigue have been found for a wide range of muscles and experimental protocols. Spectral changes due to fatigue have been attributed to decreases in action potential conduction velocity along the muscle fibre (Sadoyama and Miyano, 1981). Many studies assessing muscle fatigue have identified a decrease in mean and median power frequencies for isometric exertions (Viitasalo and Komi, 1977; Hary et al., 1982; Duchene and Goubel, 1990). For fatiguing intermittent exertions, higher sensitivity was found for median power frequencies when compared to mean power frequencies (Nussbaum, 2001). Fatigue-induced signal amplitude increase has been attributed to the recruitment of more motor units (Edwards and Lippold, 1956; Basmajian and De Luca, 1985), increased excitation rate (Bigland-Richie et al., 1986) and synchronous firing of motor units (Lippold et al., 1960). For static exertions, fatigue-induced increases in signal amplitude in the time domain are less sensitive than spectral shifts (Merletti et al., 1990; Madeleine et al., 2002).

2.6.2 Rating of perceived exertion

Borg (1982) suggested that "perceived exertion is the single best indicator of the degree of physical strain." This rating of perceived exertion is beneficial in its ability to detect overall changes in effort in a complex area such as the shoulder (Putz-Anderson, 1993). The Borg CR-10 scale (Figure 2) is a simple category scale developed using numbers coupled with verbal descriptions of the level of exertion (Borg, 1982). Perceived exertion on this scale has been linked with physiological measures of fatigue (Borg, 1990); positive correlations have been found with muscle and blood lactate levels (Noble et al., 1981), and EMG signal root mean squared amplitude (Hasson et al., 1989). Also, strong inverse associations between the rating of perceived exertion and mean power frequency of EMG signals has been found in studies investigating sub-maximal gripping tasks (Hasson et al., 1989), and isometric shoulder elevation (Hummel, 2005). Therefore, the systematic collection of ratings of perceived exertion over a period of time gives insight into the cumulative effect of muscle fatigue.



0	Nothing at all
0.5	Very, very weak (just noticeable)
1	Very weak
2	Weak (light)
3	Moderate
4	Somewhat strong
5	Strong (heavy)
6	
7	Very strong
8	
9	
10	Very, very strong (almost maximal)

Figure 2: Borg CR-10 scale

Many studies assessing overhead work incorporated use of this scale since it has proven to be a reliable measure for the progression of muscle fatigue (ex. Nussbaum, 2001; Garg et al., 2006; Sood et al., 2007). Intraclass correlation coefficients indicated excellent reliability of ratings of perceived exertion during an overhead fatiguing protocol (Sood et al., 2007).

2.6.3 Static strength capability

Static strength is defined as “the capacity to produce torque or force by a maximal voluntary isometric muscular exertion” (Chaffin, 1975). It has historically been used as a measure of worker capacity to assure he/she can meet the demands of the job (Chaffin, 1975). While this may be useful for jobs requiring high levels of force, it’s predictions for worker capacity in light-load jobs is not well correlated (Wiker et al., 1990). Also, strength capability is specific to the posture in which it is measured. Haslegrave and colleagues (1997) found that strength in an overhead posture is significantly decreased compared to a neutral posture.

Static strength has also been used as a physiological measure of muscle fatigue through decrements in force production. Physiologically, the decrement in force production can be attributed to the imbalance of Na^+ and K^+ across the sarcolemma which alters propagation of action potentials (Sejersted, 1992). This imbalance inhibits the release of calcium from the sarcoplasmic reticulum, resulting in less actin-myosin binding within the sarcomeres of the muscle fibre (Vollestad, 1997).

Vollestad and Sejersted (1988) defined fatigue as “any exercise-induced reduction in the maximal capacity to generate force output”. Following this definition, the systematic collection of static strength capability throughout an experiment would give insight into the progression of muscle fatigue over time. The isometric static strength test was deemed reliable through high test and re-test correlations (Hazard et al., 1993; Ylinen et al., 1999) and low coefficients of variation (Keyserling et al., 1980).

2.6.4 Endurance time

In terms of muscle contraction, endurance time is the length of time skeletal muscle can maintain a required force until the muscle fails to do so, indicating fatigue (Hagberg, 1981). In order to quantify muscle fatigue during prolonged tasks, the maximum endurance time is commonly used. When the concept of endurance time was introduced, many studies evaluated static exertions over a range of constant forces (Rohmert 1973a; 1973b; Hagberg, 1981). Specifically for static overhead exertions, upper arm elevation was found to have a significant effect on endurance time (Garg et al., 2002). Intermittent contractions induce periods of rest and have been found to induce higher endurance limits (Bjorksten and Jonsson, 1977). This holds true for intermittent tasks performed in overhead postures as well.

Changes in duty cycle had significant effects on endurance time for intermittent overhead tasks (Nussbaum et al., 2001).

Rohmert was the first to report that plotting endurance time across different force intensities resulted in a hyperbolic function (Figure 3). Using this relationship, the endurance limit is defined as the force at which a static contraction can be held indefinitely. Rohmert's endurance limit curve suggests that a worker can maintain a static force less than 15% of their maximal force, without any rest allowances. Since Rohmert (1973a) defined an indefinite holding time by a trial of 10 to 15 minutes, it is no surprise that trials of 60 minute static exertions elicited a much smaller endurance limit of 7.9% of the maximal force (Bjorksten and Jonsson, 1977). Also, endurance times are affected by the weight of body segments, therefore, one simplistic endurance limit does not apply across different joints in the body (Rohmert et al., 1986). Through a meta-analysis of studies involving static exertions maintained until fatigue, a power model of the intensity-endurance time relationship was evaluated for different joints (Frey Law and Avin, 2010). Out of the joints investigated, the shoulder had the lowest endurance times indicating that it was the most fatigable (Figure 4). Garg and colleagues (2002) found similar trends when examining endurance time and force for static overhead exertions at varying postures. Even though the hyperbolic intensity-endurance time relationship was replicated, the curve never becomes asymptotic at low levels of force, indicating that an endurance limit does not exist for the shoulder (Garg et al., 2002; Frey Law and Avin, 2010).

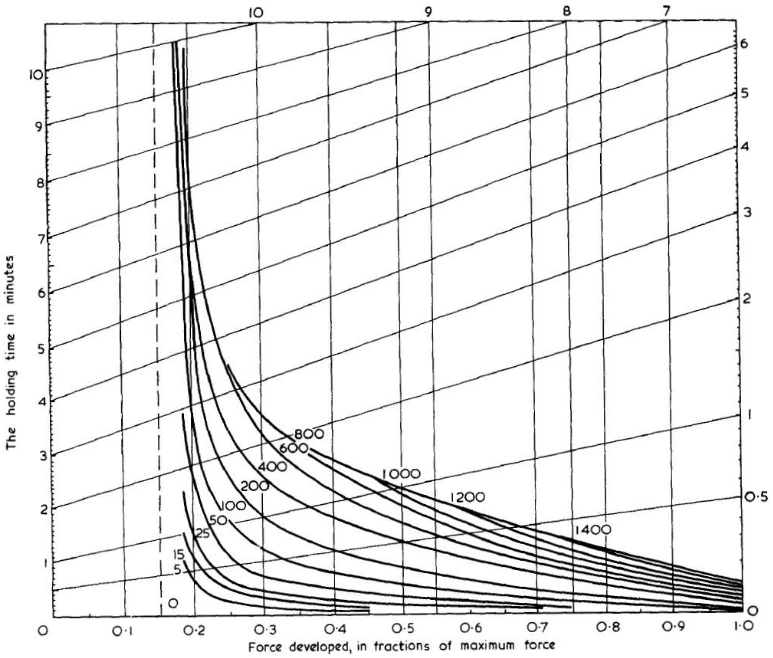


Figure 3: Percentage rest allowances for various combinations of holding forces and times (adapted from Rohmert, 1973)

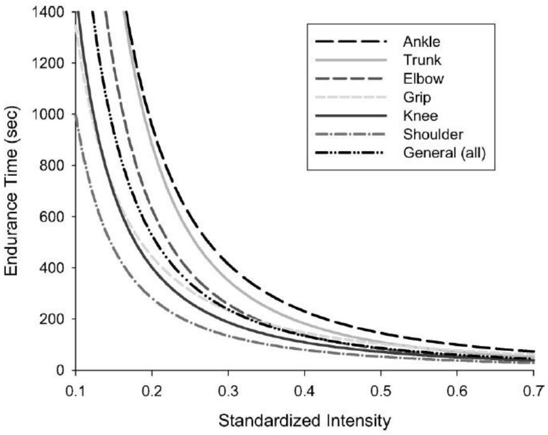


Figure 4: Joint specific power fatigue models are plotted to demonstrate relative differences in fatigue resistance (endurance time) as a function of contraction intensity (adapted from Frey Law and Avin, 2010).

3.0 Methods

3.1 Participants

Ten university aged (21.6 years, +/- 1.9 years), right-handed females having an average weight of 65.6kg (+/- 11.3kg) and an average height of 163.4cm (+/- 7.1cm) participated in the study. However, the data of nine participants were used for analysis since one individual did not adhere to the protocol for the last testing session. Previous studies have shown that females have significantly lower upper body strength capabilities compared to males (Bishop et al., 1987; Miller et al., 1993). Since a large proportion of the male population is capable of performing tasks at higher workloads, researching safe thresholds for women is a conservative approach. Also, since 2000, the amount of lost time claims filed by females has increased as a percentage of total lost time claims (WSIB Statistical Supplement, 2009). This trend may be partially due to an overall increase of females in the labour market since 1976 (Ferrao, 2010). In order to support the decrease of work-related injuries experienced by females, research should be focused on defining safe working conditions for female industrial workers.

Inclusion was based on the participants not having any type of shoulder injury within the past year, and no known allergies to isopropyl alcohol. Before performing experimental trials, participants were briefed about the study protocol and asked to sign the consent forms, which were approved by the University of Waterloo Office of Research Ethics.

3.2 Experimental design

A repeated measures design was used. The four testing sessions were scheduled one week apart since each session required the participant to work until fatigue. In order to avoid intra-subject variability for static strength and EMG measures, participants performed each testing session at the same time of day (Wyse et al., 1994).

3.2.1 Variables of interest

One independent variable, cycle time, was manipulated for each experimental condition. Each cycle included one rotation between a neutrally located assembly task and an overhead task. Four cycle times were investigated (Figure 5): 120s, 60s, 30s and 15s. To maintain a constant exposure of work across all conditions, work was performed in two minute blocks at a 40% duty cycle of overhead work. Within the overhead task were two sub-tasks, press and release, which were performed at a 50% duty cycle. The press phase required participants to exert a force which was normalized to 30% of overhead static strength, and the release phase was simply not producing force while maintaining the overhead posture. Large differences in relative shoulder exposure existed between the overhead and neutral tasks due to a change in external moment primarily from postural changes. As a result of the presence or absence of force application, discrepancies in exposure level at the shoulder also existed within the overhead task. Figure 6 describes the relative exposure between the tasks based on muscle activation levels of the middle deltoid during each task. The neutrally located task allows the external shoulder moment to remain low (10% of maximal exposure), whereas the generation of large external moments in the overhead posture increases exposure (70% of maximal exposure). The application of force in the overhead posture further increases shoulder exposure to the maximum level experienced within the protocol.

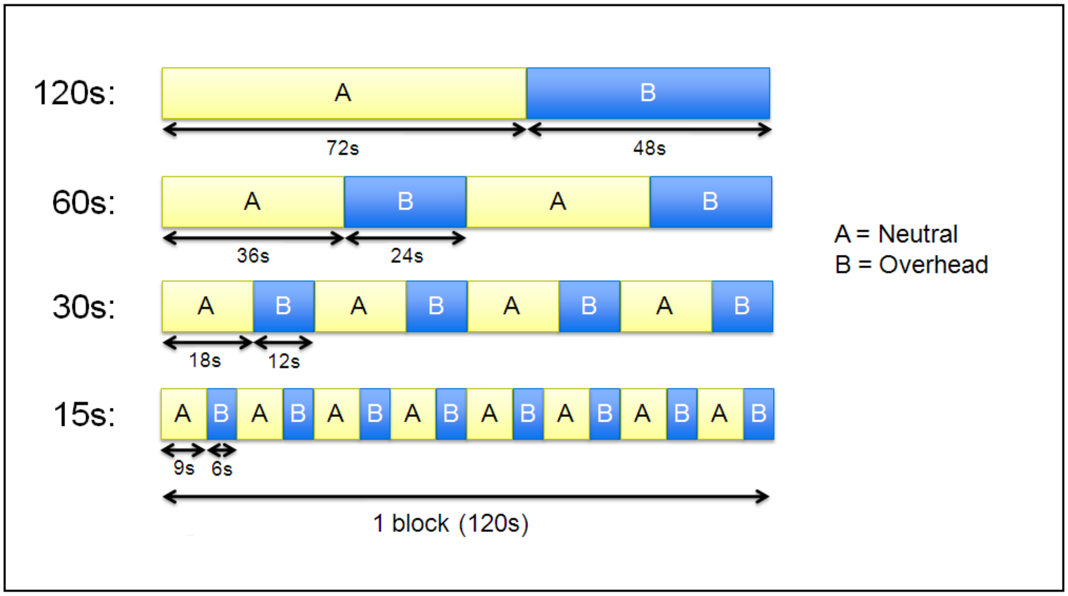


Figure 5: Schematic of each condition

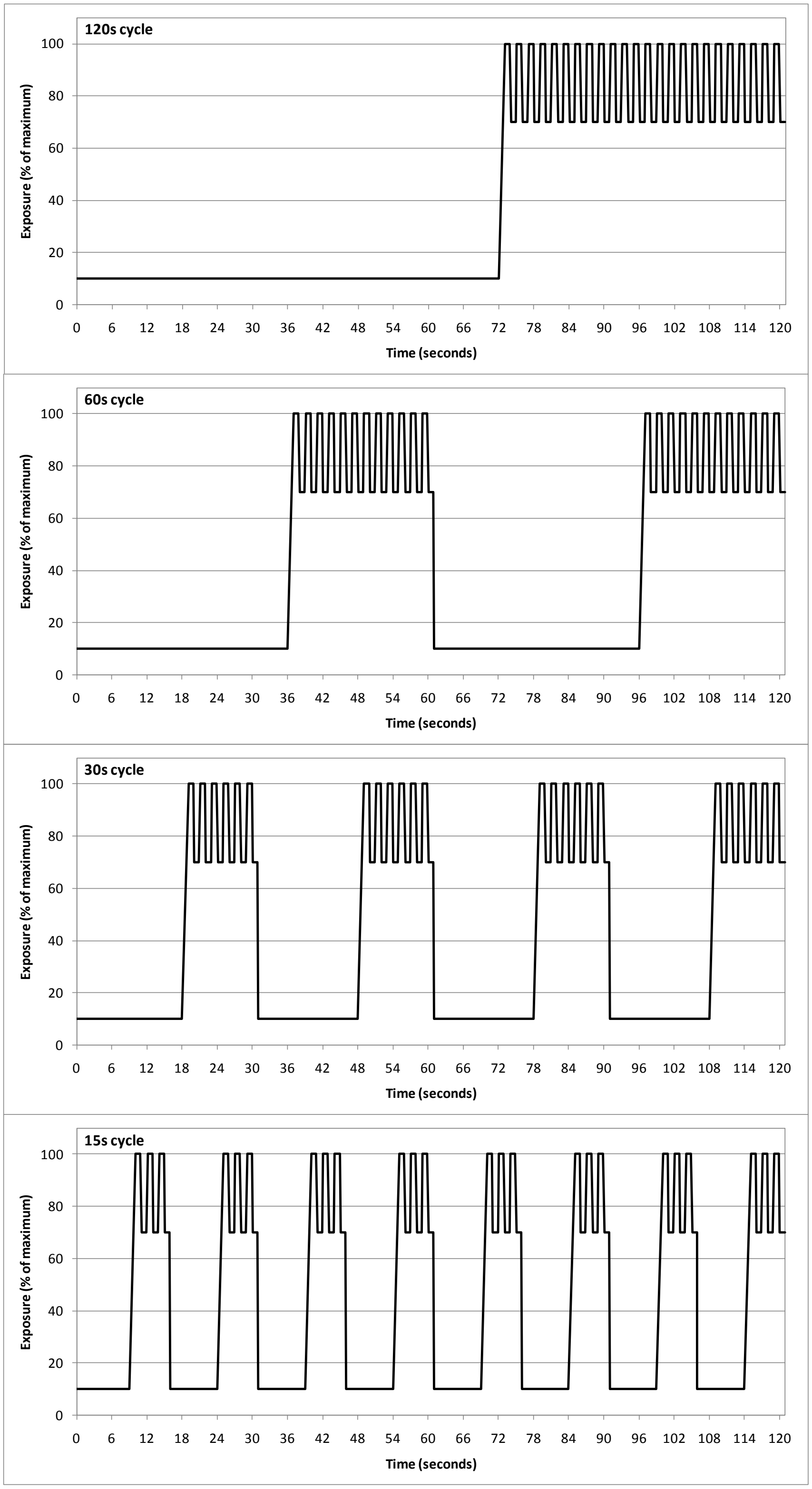


Figure 6: Conceptual exposure versus time graphs of each condition over a two minute block

Four dependent variables were systematically measured throughout the experimental conditions, and assessed as time-varying indicators of fatigue. Surface electromyography of nine shoulder muscles (anterior, middle, and posterior deltoid, supraspinatus, infraspinatus, upper, middle and lower portions of the trapezius, and the clavicular insertion of pectoralis major) were measured to determine changes in normalized root mean squared (RMS) amplitudes and median power frequencies (MdPF). Generation of maximal force in a static overhead posture was measured using a static strength capability test. As a subjective measure of fatigue, the rating of perceived exertion of the shoulder was determined using the Borg CR-10 scale. The fifth dependant variable, endurance time, was defined as the duration until exhaustion, or until one of the stopping criteria (refer to Section 3.4.2) was met. A summary of the described variables is displayed in Table 1.

Table 1: Summary of experimental variables

Independent Variable	Dependent Variables
Cycle time (120s, 60s, 30s, and 15s)	Surface electromyography (RMS and MdPF)
	Static strength capability (measured in overhead posture)
	Rating of perceived exertion (Borg CR-10 scale)
	Endurance time (duration in minutes)

3.3 Equipment

3.3.1 Surface electromyography

The Noraxon Telemyo 2400T G2 system along with nine bipolar Ag-AgCl electrodes (Noraxon, Scottsdale, AZ, USA) was used to measure muscle activation from selected muscles surrounding the shoulder complex. Each electrode pair has a fixed 20mm inter-electrode spacing, and was placed parallel to the muscle fibres on the muscle belly of nine shoulder muscles (Table 2). To minimize impedance of the signal, skin was prepared by shaving the area and cleansing with isopropyl alcohol before applying electrodes. In order to assure consistent placements over testing days, skin was marked using a permanent marker and photographs were taken after all electrodes had been applied. Within the pre-amplifier, signals were differentially amplified using a common mode rejection ratio of >100dB at 60Hz and input impedance of 100MΩ. Also, analog signals were band pass filtered at 10 – 500Hz to include only the physiological range of frequencies for human surface electromyography. A gain of 1000 was applied to all channels. Vicon 1.2 software (Vicon Motion Systems, Oxford, UK) was used to synchronously sample the analog signals at a rate of 1500Hz. A 16 bit A/D card was used with a maximum range of +/- 10V. Gains were adjusted to the individual channels to ensure maximum resolution of the digital signal.

Table 2: Surface electrode placements (Criswell, 2011)

Muscle	**Electrode Placement**
Anterior deltoid	Approximately 4 cm below the distal end of the clavicle on the anterior aspect of the arm
Middle deltoid	Approximately 3 cm below acromion on the lateral aspect of the arm
Posterior deltoid	Approximately 2 cm below the lateral boarder of the scapular spine
Supraspinatus	Directly above lateral aspect of the scapular spine, over the suprascapular fossa
Infraspinatus	Approximately 4 cm below and parallel to the scapular spine, over the infrascapular fossa
Pectoralis major (clavicular)	On an oblique angle towards the clavicle, approximately 2 cm below the clavicle and medial to the anterior axillary fold
Upper trapezius	Slightly lateral to and one half of the distance between the C7 spinous process and the acromion
Middle trapezius	Medial to the medial boarder of the scapula at the level of the trigonum spinae
Lower trapezius	Approximately 5 cm below the trigonum spinae, adjacent to the medial boarder of the scapula at a 55° oblique angle

3.3.2 Workstations

The location of workstations was dependent on the task performed: overhead versus neutral. Participants remained seated throughout the entire collection. Seat height was normalized to each participant by adjusting the height of the seat to assure the included knee angle was 90° while the feet were in full contact with the floor. In some cases, the use of a foot rest was required. The height of the backrest was also normalized to each participant, and defined the upright posture to be maintained throughout the protocol. During the neutral task, the backrest assisted in off-loading the weight of the upper body allowing the erector spinae musculature to relax (Corlett and Eklund, 1984). Since participants were required to sit for long periods of time, this intervention was necessary to assist in the prevention of low back pain (Andersson, 1981). During the overhead task, participants were instructed not to use the backrest in order to isolate force production at the shoulder.

The neutral workstation was located at 0° shoulder abduction, 0° shoulder flexion, and 90° elbow included angle (Figure 7). A height-adjustable desk was used set the location of the workstation. Seat location was dependant on the set up of the neutral workstation. The horizontal location of the seat was centered with respect to the desk location. A distance of 30cm between the front of the desk and the centre of the torso at umbilicus height defined the vertical seat location.

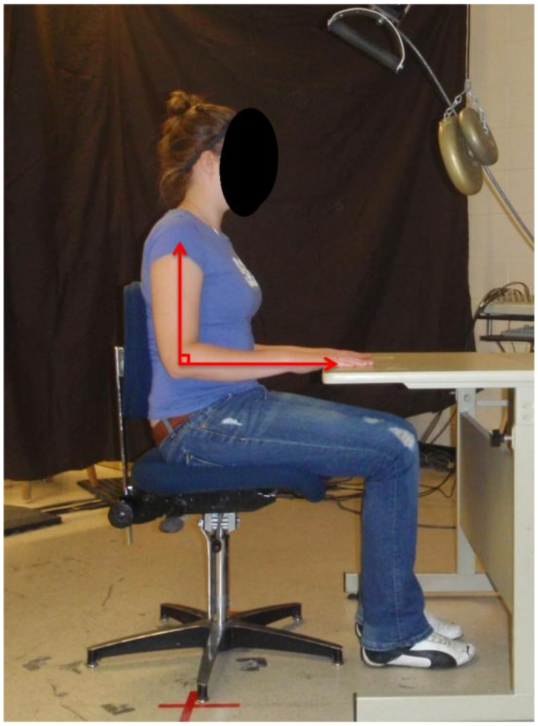


Figure 7: Neutral task posture

The location of the overhead workstation was set following the positioning of the neutral workstation. For the overhead task, the arm was positioned at 0° shoulder abduction, 120° shoulder flexion, and 150° elbow included angle (Figure 8). Through a previous overhead work study, this posture was found to be common in automotive assembly (Garg et al., 2005). The overhead work location was programmed into the Motoman HP50N robotic arm (Yakasawa Motoman, Mississauga, ON, Canada). Consistency of workstation locations was crucial since the collection protocol required participants to complete experimental conditions on different days. The repeatability of locations programmed into the robotic arm was +/- 0.07mm. Attached to the robotic arm was a proprioceptive feedback device attached in series with a force transducer/handle interface. Force was measured using a six degree of freedom, multi-axis load cell (MC3A; ATMI, Watertown, MA, USA) with a metal cylinder mounted on the end to serve as a handle. Participants were instructed to grip the handle in the centre of the cylinder using a power grip when performing the overhead task.

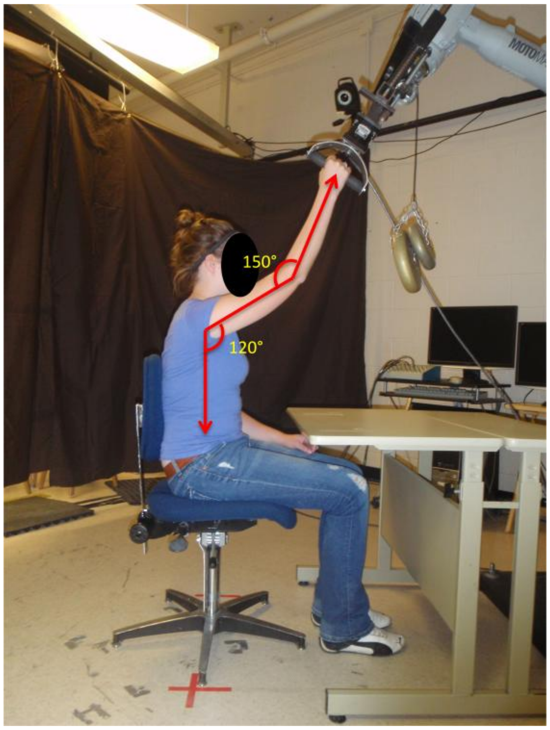


Figure 8: Overhead task posture

3.3.3 Force feedback modalities

During the overhead tasks, participants were required to intermittently exert 30% of their maximal static strength. Proprioceptive feedback was used to ensure a constant level of force was exerted for the entire press phase of the overhead task. The proprioceptive feedback device (Figure 9) was controlled using a dial to adjust the tension of a spring, and a stopper to restrict movement of the device (adapted from Potvin et al., 2006). Adjustment of the tension dial controlled the length of the threaded rod (5 threads/cm) which, when tightened, displaced the lower bar (attached to the force transducer) upwards and compressed the spring (resting length: 1.25coils/cm). A washer with rubber padding was fixed onto the threaded rod and used as a stopper to allow the spring to compress over a distance of 1.3cm. When the spring compressed to the stopper, the required force was achieved and was maintained for the entire force production phase. Gliding of cylindrical bars through ball bearings enabled movement of the lower bar while minimizing friction. The weight of the device was offloaded using a counter-weight of 3.4kg.

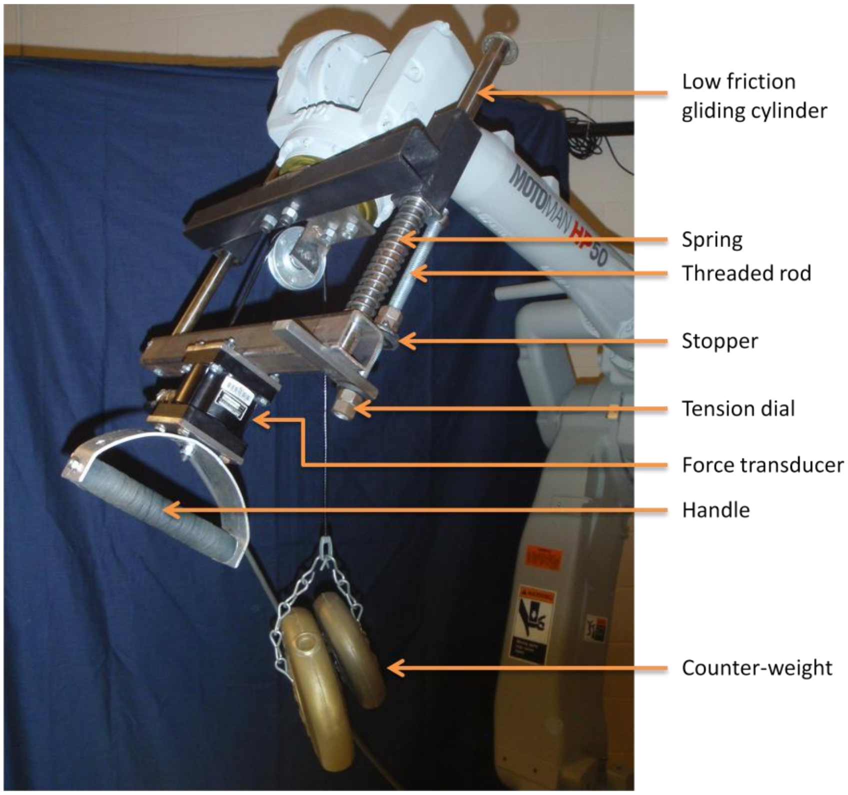


Figure 9: Proprioceptive feedback device

Real-time visual feedback was provided through a custom Labview (National Instruments, Austin, TX, USA) program. The resultant applied force was displayed using a bar graph, and thresholds were marked by horizontal lines at the 30% force level and +/- 10% (Figure 10). Visual feedback was initially used to calibrate the proprioceptive feedback device so movement stopped at the 30% force level. Also, visual feedback was useful in monitoring any forces produced on the handle during the release phase of the overhead task. This was especially important to detect a downward pulling force from off-loading the weight of the arm by hanging onto the handle. By visually monitoring these forces and correcting participants, it ensured that the release phase was not used as a method of rest.

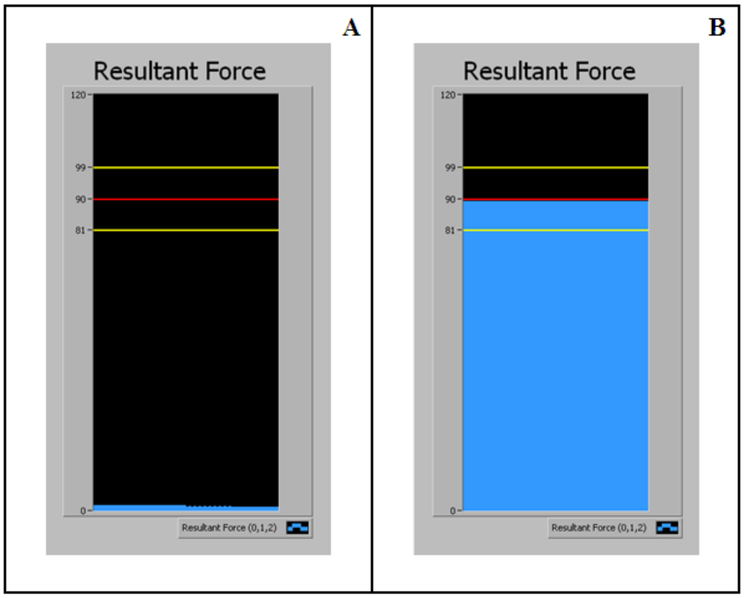


Figure 10: Visual feedback of the resultant force during the release phase (A) and force production (B) phase for a 30% force level of 90N

3.4 Collection protocol

Every collection was completed within the Digital Industrial Ergonomics and Shoulder Evaluation Lab at the University of Waterloo. After completion of the study, participants were compensated $10/hour, to a maximum of $100.

3.4.1 Training session

Each participant attended one training session before completing the experimental conditions. During this session, participants were given a description of the study and consent forms. If the inclusion criteria were met and the individual agreed to participate by signing the consent forms, initial measurements were taken:

1. Anthropometric measurements
2. Positioning of workstations
3. Maximum static strength

Anthropometric measurements consisted of height, weight, hand length, upper arm length, forearm length and torso length. Secondly, the workstation locations were normalized to each participant. The overhead workstation location was programmed into the robotic arm and the neutral workstation height was measured and recorded for setup of the experimental conditions. Finally, a minimum of three static strength trials were completed in the overhead posture with a two minute rest period between each trial (Chaffin, 1975; Mathiassen et al., 1995). Participants were asked to exert a maximal force with a power grip, positioning their hand in centre of the handle while maintaining an up-right posture (dictated by the back rest) while keeping both feet flat on the ground. Verbal encouragement was given by the researchers during maximal exertions to elicit a maximal effort from participants (McNair et al., 1996). Static strength was recorded as the average of the middle three seconds of a five second maximal static contraction (Chaffin, 1975). Considering the two highest values were within 10%, the largest value was recorded as the maximum static strength. If not, a fourth trial was taken. In order to maintain a consistent workload across experimental conditions, the force required for the overhead work task was normalized to 30% of the highest static strength value.

Following measurements, an introduction to the overhead task and neutrally located assembly task was given. Familiarization of the testing protocol included practice working at the defined pace and rotating between tasks at all four conditions. The first testing session was scheduled one week following the training session.

3.4.2 Testing sessions

Each testing session involved a different cycle time condition and was separated by a minimum of one week to allow recovery from possible muscle fatigue experienced from previous sessions. Each session began with setting the workstations to the appropriate location determined in the training session.

A series of baseline measures and maximal voluntary isometric exertions (for EMG normalization purposes) were taken before the collection of each experimental condition. Firstly, a baseline measure of the rating of perceived exertion was taken. If the participant had a rating higher than zero, the session may need to be rescheduled due to residual fatigue, or the participant may no longer be able to participate in the study due to an injury. Surface electrodes were then applied over the nine shoulder muscles of interest and three isometric maximal voluntary contractions in the overhead posture were performed. Each maximal trial was collected over five seconds, and verbal encouragement provided by the researchers served as motivation to assist in achieving a maximal effort (McNair et al., 1996). To allow for adequate recovery, a two minute rest period was given between each maximal exertion (Chaffin, 1975; Mathiassen et al., 1995). The three maximal voluntary exertions also served as a measurement of static strength since the applied force was exerted in the same overhead posture as the training day. After another two minutes of rest, a baseline measure of muscle activity in a reference overhead exertion was collected. For the reference exertion, the participant used the same overhead posture, but the target force was normalized to 30% of their maximum static strength (collected on the training day).

Following the initial testing, collection of the protocol commenced. Auditory cues were set at intervals specific to each cycle time condition to indicate when to switch tasks. Regardless of the condition being tested, the protocol started with the neutral task. This task consisted of an assembly task similar to a hand dexterity test (Figure 11). The process involved picking up a washer with the left hand, a peg with the right hand, and then lining up the washer with a hole on the pegboard before inserting the peg. This process was repeated for the duration of the neutral task at a controlled pace of 0.333pegs/s. This pace was chosen since it was lower than the average maximal pace (0.4pegs/s) making quotas easily attainable. Since cycle time was altered for each condition, the quota for each neutral task changed accordingly. The number of pegs assembled for each neutral task rotation was recorded for the duration of the protocol. Participants were allowed to off-load the weight of the arms by resting their forearms on the workstation table. Since this task required such a low hand force and low shoulder postural load, it was designed to give shoulder muscles an active rest.

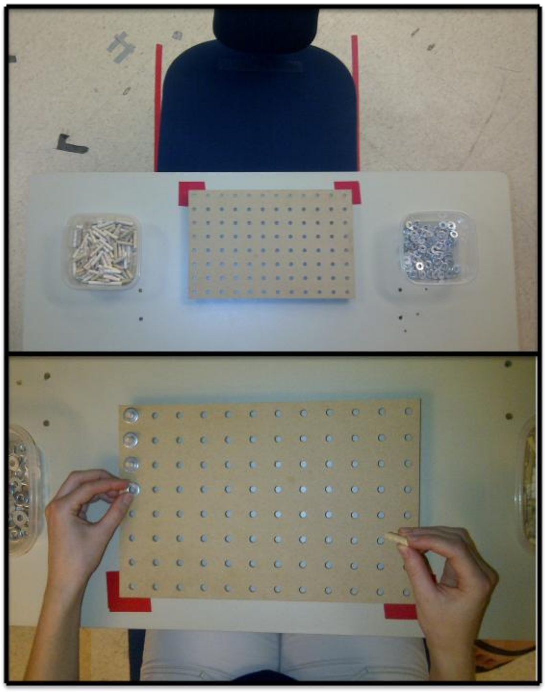


Figure 11: Neutrally located assembly task

The overhead task was an intermittent upward pushing task using a power grip on a cylindrical handle. The rationale behind choosing an upwards push was two-fold: to keep the wrist in a neutral posture, and to perform an occupationally relevant task. In order to focus on the effect of overhead work on the shoulder, it is important to limit the probability of discomfort or fatigue in other joints, such as the wrist, by avoiding awkward postures. This task had high occupational relevance since the threshold of force and power grip on a handle mimics tasks such as drilling (Anton et al., 2001) or assembly requiring a hand tool interface.

The amount of force required for the press phase of the overhead task was normalized to 30% of the participants' static strength recorded during the training session. The overhead task was set at a duty cycle of 50% and a pace of 60 beats per minute. The participant followed the pace using the beat of a metronome; one beat signaled the application of force for 1 second, the next beat signaled removal of the force for 1 second. This was continued for the remainder of the overhead task, and all other overhead tasks within the condition.

Dependent variables were systematically collected throughout the conditions (Figure 12). Rating of perceived exertion, RMS amplitude and median power frequency were assessed immediately after every 2nd block (4 minutes). However, a static strength test was only performed after every 4th block (8 minutes) to avoid any possible contribution to fatigue (ex. Nussbaum et al., 2001; Sherman, 2003; Sood et al., 2007). Collection of EMG within tasks was completed over every 4th block (2 minute trial).

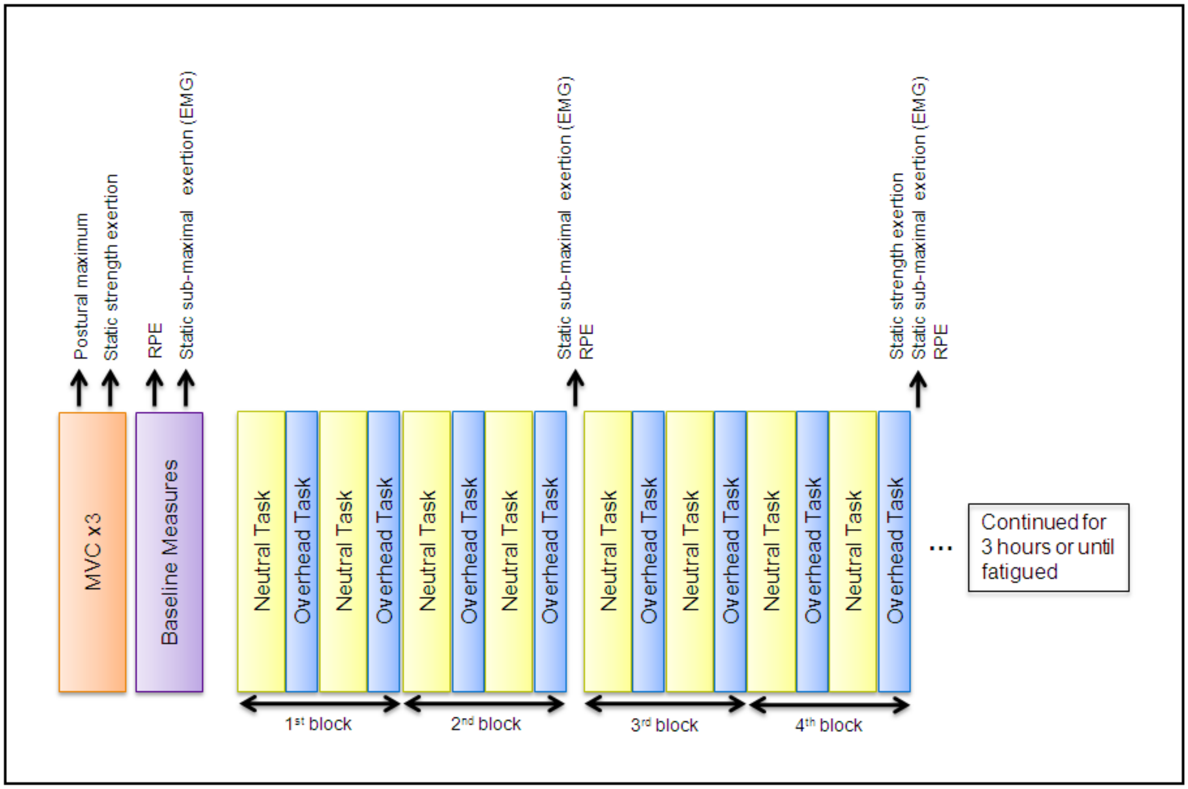


Figure 12: Schematic of collection protocol for 60s condition

In order to protect participants from working while fatigued, four protocol stopping criteria were used. Testing ceased when the one of the following criterion was met:

- The participant expressed that she no longer had the physical capacity to continue
- Static strength decreased below 70% of maximal static strength over three consecutive trials
- Rating of perceived exertion increased above a rating of 7 on the Borg CR-10 scale over two consecutive trials (ex. Nussbaum et al., 2001)
- The condition lasted for three hours since intermittent overhead work is rarely performed consecutively for longer (Nussbaum et al., 2001).

3.5 Data reduction

3.5.1 Surface electromyography

Signal processing was completed using custom MATLAB software (The MathWorks Inc., Natick, MA, USA). Trials from the within-task collections were selected for processing. Visual inspection of signals and windowing of the phases within the overhead task, and the neutral task was completed prior to signal processing. The middle 500ms of the last three overhead presses and releases from every 4th block were selected for processing. Force tracings were used to define the middle 500ms window. For the neutral task, three 500ms windows were evenly spaced over the last three seconds of the task from every 4th block.

Processing of the maximal trials preceded the sub-maximal (within-task) trials. Firstly, the three maximal trials were processed using a 500ms moving RMS window after removal of signal bias, and the highest RMS activation within the middle 3s was selected from each trial. The maximum activation out of the three trials was chosen for amplitude normalization of the sub-maximal trials. Secondly, sub-maximal signals were initially processed by removing DC bias. Signals were high-pass filtered using a 4th order Butterworth filter with a cutoff frequency of 30Hz to remove heart rate contamination (Drake and Callaghan, 2006). A Fast Fourier transform was performed and median power frequency (MdPF) was calculated over each 500ms window (Oberg, 1994) and the three values were averaged. To calculate EMG amplitude, the RMS of the signal was calculated over the same three 500ms windows and averaged. RMS values from sub-maximal trials were normalized to the peak RMS derived from maximal trials. For the purpose of fatigue analysis on the overhead press phase, both MdPF and RMS values were normalized to baseline in order to compare results across conditions.

3.5.2 Static strength capability

The resultant force from each maximal overhead exertion was used to determine static strength. More specifically, static strength was calculated by averaging the middle three seconds of a five second trial. The maximal static strength produced on the training day was used to normalize static strength values for all conditions. To allow for comparison across conditions, average static strength of each condition was normalized to baseline values.

3.6 Statistical analyses

Initially, regression analysis was performed on fatigue measures over time. The type of regression analysis (linear or exponential) was based on the highest average coefficient of determination (r^2) over all trials within a dependant measure. A linear fit was deemed appropriate for rating of perceived exertion over time (r^2 ranging from 0.4498-0.9827) and static strength over time (r^2 ranging from 0.0009 to 0.7860). However, EMG measures had poor fits for both types of regression. Linear regression produced highest r^2 values overall, but the average was less than 0.3. Refer to Appendix D for results of this analysis.

A secondary analysis of EMG measures over time required time to be normalized to completion time. Data points of dependant variables were divided into 8 equal bins of time and averaged within each bin. Assessment of normality for each dependant measure was completed using q-q plots of the residuals. For MdPF and RMS amplitude, individual 2-way repeated measures ANOVA were used to assess the influence of cycle time condition (120s, 60s, 30s and 15s) and time on each measure of fatigue. The assumption of sphericity was assessed using Mauchly’s criterion. If variances in the differences between conditions were not equal, the Huynh-Feldt (H-F) estimate was used as a correction factor to adjust the p-value. An alpha level of 0.05 was used to identify a significant effect of condition and time on dependant measures. Statistically significant effects were examined post-hoc using a Tukey HSD test to identify significant differences.

Endurance times and slopes of rating of perceived exertion and static strength utilized the same statistical test. A one-way repeated measures analysis of variance was used to assess the influence of cycle time condition (120s, 60s, 30s and 15s) on each dependant variable. Similarly to EMG measures, the assumption of sphericity was assessed using Mauchly’s criterion. If variances in the differences between conditions were not equal, the Huynh-Feldt (H-F) estimate was used as a correction factor to adjust the p-value. An alpha level of 0.05 was used to determine significance, and a post-hoc Tukey HSD test indicated significant differences between conditions.

Effect size of condition was assessed for all dependant measures using partial eta squared (η_p^2). For the 2-way ANOVA used for EMG measures over time, the effect size of condition and time were assessed. The proportion of variation attributable to each factor can be interpreted using the following benchmarks: 0.01 = small, 0.06 = moderate and 0.14 = large (Cohen, 1988).

Maximum static strength collected on the training day and for each testing session was presented using descriptive statistics to report variability of static strength from day to day. Assessment of variability was completed by calculating means and standard deviations of each participant’s static strength. Correlation was used to investigate whether there was a relationship between daily maximal static strength and fatigue measures for each condition. The strength of the relationship was evaluated through linear regression and quantified using the coefficient of determination (r^2).

4.0 Results

In order to assess fatigue related differences due to changes in cycle time, five dependant variables were evaluated. Firstly, differences in endurance time across the four conditions were identified. Quantification of muscular demand through EMG RMS revealed which muscles were primarily involved in performing the overhead task and determined which muscles to include in the fatigue analysis. To compare the rate of fatigue development between conditions, linear regression was used on EMG measures (RMS and MdPF), rating of perceived exertion, and static strength capability over time.

4.1 Endurance time

Commonly used as a measure of fatigue during prolonged tasks, endurance time was recorded to identify whether alteration of cycle time affected the length to which the tasks could be performed. It was found that the condition significantly affected completion time (F[3,24]=3.96, p=0.02). Participants were able to perform the condition with the 15s cycle time longer than the 120s cycle time (Figure 13). Average completion times of the 60s and 30s conditions (131.11 and 140.89 minutes, respectively) were between the 120s and 15s conditions and their average durations were statistically the same as both the 120s and 15s cycle time conditions (Table 3). However, in each condition, at least one participant was able to continue the protocol to the 3 hour mark (Table 4). Specifically for the 15s cycle, over half of the participants completed the protocol at the 3 hour stopping criterion, making average completion time an underestimate of true endurance time. Also, a partial eta squared of 0.33 indicates that condition had a large effect on endurance time.

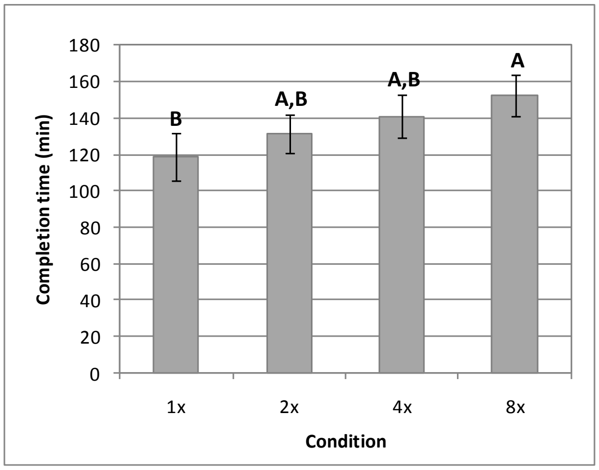


Figure 13: Average completion times for each cycle time condition

Table 3: Results of one-way repeated measures ANOVA and post-hoc test assessing significant differences in completion time

Condition	Mean	SE	F Ratio	P Value	Tukey HSD	η_p^2
120s	118.67	12.74	3.96	0.02	B	0.33
60s	131.11	10.39			A,B	
30s	140.89	11.85			A,B	
15s	152.44	11.18			A	

Table 4: Completion times across cycle time conditions and participants

Participant	Completion time by condition			
	120s	**60s**	**30s**	**15s**
P01	64	112	128	136
P02	180*	180*	180*	180*
P03	140	108	108	108
P04	152	112	180*	180*
P05	128	152	168	180*
P06	64	128	108	116
P07	104	80	96	112
P08	112	152	120	180*
P09	124	156	180*	180*
Average	**118.67**	**131.11**	**140.89**	**152.44**
SD	*38.21*	*31.16*	*35.54*	*33.55*

***** indicates that protocol was stopped at 3 hour mark and is not a measure of endurance

4.2 Overall muscular demand as indicated by EMG

The activation of several muscles was monitored during performance of tasks throughout the protocol to provide a holistic view of the contribution of muscles surrounding the shoulder. The first analysis included comparisons of muscle activation between muscles within each task. Establishing which muscles were primarily involved during the press phase of the overhead task guided the selection of muscles included in the fatigue analysis. A second analysis compared muscle activation between the two phases of the overhead task and the neutral task. Quantification of the change in muscular demand between tasks was achieved through calculation of activation ratios for each muscle. For both analyses, comparisons in activation were based on the RMS amplitude (%MVC) of each muscle which was averaged over the last 25% of the protocol.

4.2.1 Comparison of muscle activation within tasks

Examination of the overhead task during the press phase revealed seven muscles that were highly activated. These muscles included middle deltoid, supraspinatus, middle trapezius, upper trapezius, anterior deltoid, posterior deltoid, and infraspinatus. Specifically for the 120s condition (Figure 14), muscle activation for these muscles ranged between 32%MVC and 50%MVC. For the other conditions (Appendix B), the same muscles were predominantly active, but activation was lower and ranged from 18%MVC to 41%MVC. Other than the 120s condition, the middle deltoid was the most highly recruited muscle for the press phase of the overhead task (120s: 41%MVC, 60s: 36%MVC, 30s: 32%MVC, 15s: 41%MVC). Across all conditions, activation of supraspinatus, middle and upper trapezius remained at levels similar to middle deltoid. The 120s condition is the only case in which activations of supraspinatus, middle and upper trapezius increased above middle deltoid (Figure 14). Anterior deltoid and infraspinatus were consistently lower than the four previously described muscles, and had similar activation levels to each other (120s: 36%MVC and 32%MVC, 60s: 27%MVC and 27%MVC, and 30s: 25% MVC and 24%MVC, 15s: 28% MVC and 31%MVC, respectively). Aside from the 120s condition, posterior deltoid had the lowest activation out of the seven muscles for all conditions (60s: 23%MVC, 30s: 18%MVC, 15s: 24%MVC). Posterior deltoid had a similar level of activation as anterior deltoid and infraspinatus in the 120s condition (34%MVC).

Inclusion of muscles in the fatigue analysis was based on activation levels in the press phase of the overhead task. Seven muscles were selected due to relatively high levels of recruitment, indicating involvement in performing the task. These muscles included middle deltoid, supraspinatus, middle trapezius, upper trapezius, anterior deltoid, posterior deltoid, and infraspinatus. The long duration of the protocol and high muscular demand of the overhead press task makes these muscles susceptible to fatigue. Since lower trapezius and pectoralis major maintained very low levels of activation (11%MVC to 16%MVC) across all conditions, they were not included in the fatigue analysis.

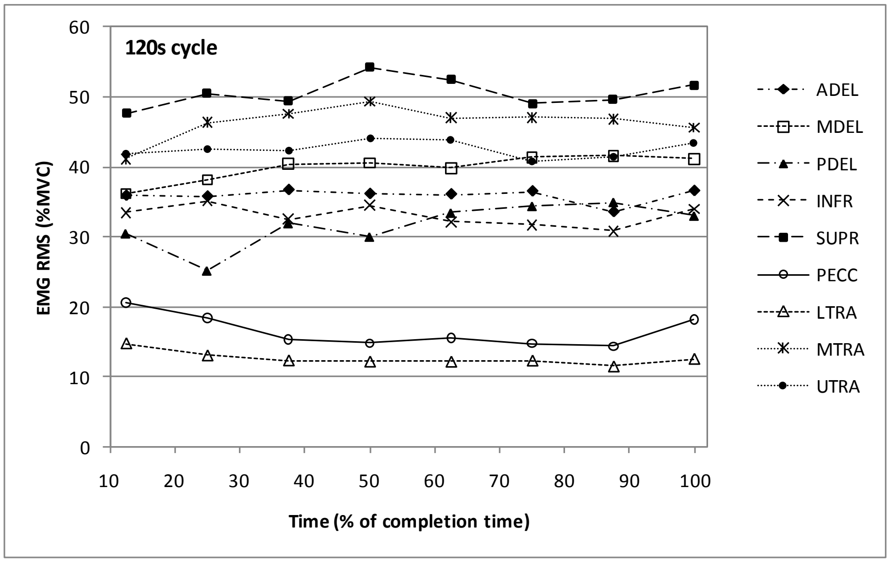


Figure 14: Activation profile of all muscles during the overhead task's press phase of the 120s cycle condition

For the release phase of the overhead task, larger discrepancies in muscle activation levels were identified across conditions compared to the press phase. During the 120s condition (Figure 15), there was a wider range of activation levels across muscles (18%MVC to 44%MVC) compared to the other conditions (Appendix B; 60s: 12%MVC to 28%MVC, 30s: 11%MVC to 28%MVC, and 15s: 14% MVC to 32% MVC). Supraspinatus and upper trapezius were the most highly activated muscles across all conditions (120s: 44%MVC and 38%MVC, 60s: 27%MVC and 28%MVC, and 30s: 26% MVC and 28%MVC, 15s: 32% MVC and 29%MVC, respectively). Middle trapezius, anterior deltoid and middle deltoid were consistently below the activation levels of supraspinatus and upper trapezius across all conditions. Aside from the 120s condition, these three muscles had extremely similar levels of activation (average RMS of the three muscles for 60s: 22%MVC, 30s: 23%MVC, and 15s: 27% MVC). Relatively similar, low levels of recruitment were revealed within each condition (120s: <23%MVC, 60s: <17%MVC, 30s: <18%MVC, 15s: <20%MVC) for infraspinatus, posterior deltoid, pectoralis major and lower trapezius.

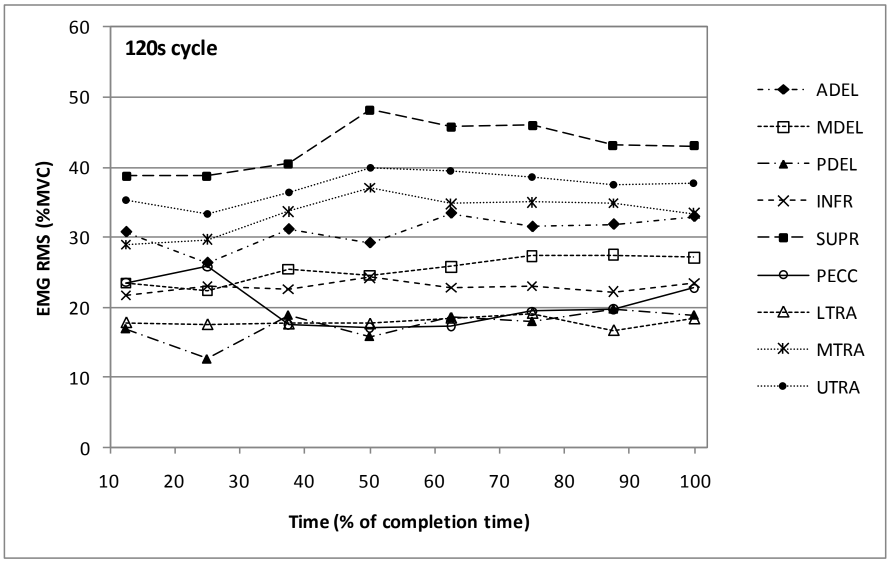


Figure 15: Activation profile of all muscles during the overhead task's release phase of the 120s cycle condition

The neutral task required very low levels of activation across all muscles. The range in activation level across conditions was 2%MVC to 20%MVC. Supraspinatus and pectoralis major had the highest activation level for the 120s (Figure 16; 20%MVC and 18%MVC, respectively), 60s (15%MVC and 18%MVC, respectively), and 15s (15%MVC and 17%MVC, respectively) conditions (Appendix B). During the 30s condition, supraspinatus followed the same trend in activation (15%MVC), but the recruitment of pectoralis major was relatively less (12%MVC) compared to other muscles. For all conditions, middle and posterior deltoid were the least activated muscles during this task with average activations ranging between 2%MVC and 4%MVC.

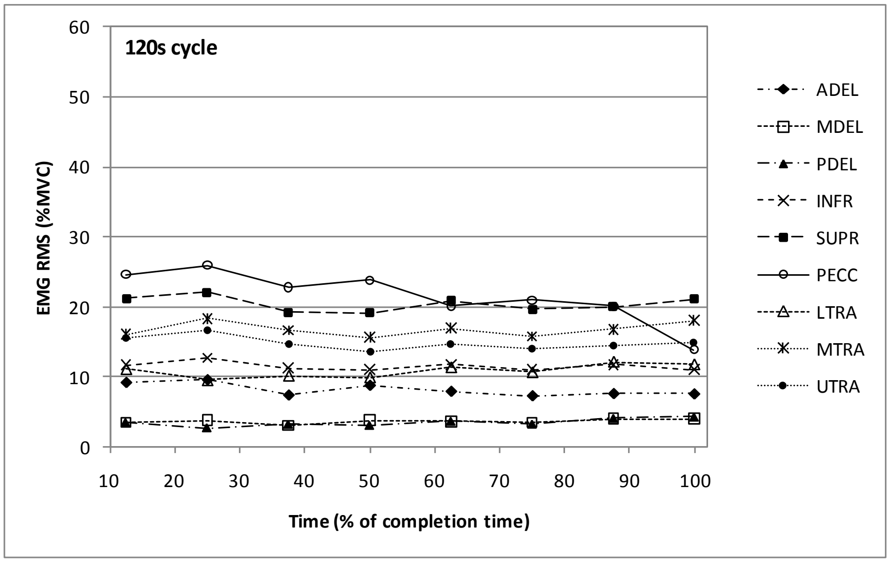


Figure 16: Activation profile of all muscles during the neutral assembly task of the 120s cycle condition

4.2.2 Comparison of muscle activation between tasks

The tasks involved in the protocol required alteration of postures and levels of force resulting in differences in overall shoulder exposure. This change in exposure between tasks results in different levels of muscular demand between tasks, and was quantified for each muscle through calculation of activation ratios (Table 5). Since the majority of muscles had low levels of recruitment during the neutral task, the activation ratios were expressed as a multiple of neutral task activation. The order in which the tasks were presented within the activation ratio was overhead task (press phase): overhead task (release phase): neutral task. Results of the 120s condition were described since the relative activation level between tasks remained consistent across conditions.

Table 5: Average EMG RMS amplitude (% MVC) of all muscles over the last 25% of the protocol for each task and condition

Muscle	**Condition**	**Overhead task: press phase (a)**	**Overhead task: release phase (b)**	**Neutral task (c)**	**Activation ratio (a:b:c)**
Anterior deltoid	120s	35.50	32.05	7.48	4.7 : 4.3 : 1.0
	60s	26.78	22.29	7.86	3.4 : 2.8 : 1.0
	30s	25.61	23.29	6.52	3.9 : 3.6 : 1.0
	15s	28.33	25.96	7.49	3.8 : 3.5 : 1.0
Middle deltoid	120s	41.36	27.31	3.83	10.8 : 7.1 : 1.0
	60s	35.70	23.46	3.92	9.1 : 6.0 : 1.0
	30s	31.86	24.17	3.32	9.6 : 7.3 : 1.0
	15s	40.58	28.33	3.79	10.7 : 7.5 : 1.0
Posterior deltoid	120s	34.11	18.86	3.85	8.9 : 4.9 : 1.0
	60s	22.97	12.16	2.66	8.6 : 4.6 : 1.0
	30s	18.28	10.86	2.18	8.4 : 5.0 : 1.0
	15s	23.54	14.33	3.36	7.0 : 4.3 : 1.0
Infraspinatus	120s	32.18	22.88	11.27	2.9 : 2.0 : 1.0
	60s	27.23	17.38	11.76	2.3 : 1.5 : 1.0
	30s	24.40	17.19	7.11	3.4 : 2.4 : 1.0
	15s	30.45	19.98	10.00	3.0 : 2.0 : 1.0
Supraspinatus	120s	50.10	44.04	20.25	2.5 : 2.2 : 1.0
	60s	33.53	27.33	14.74	2.3 : 1.9 : 1.0
	30s	29.17	25.55	15.21	1.9 : 1.7 : 1.0
	15s	35.27	31.88	15.32	2.3 : 2.1 : 1.0
Pectoralis major	120s	15.76	20.63	18.30	0.9 : 1.1 : 1.0
	60s	13.13	16.65	17.47	0.8 : 1.0 : 1.0
	30s	10.61	11.77	10.92	1.0 : 1.1 : 1.0
	15s	12.54	13.77	16.71	0.8 : 0.8 : 1.0
Lower trapezius	120s	12.15	18.08	11.51	1.1 : 1.6 : 1.0
	60s	13.13	15.58	9.06	1.5 : 1.7 : 1.0
	30s	10.88	17.93	9.30	1.2 : 1.9 : 1.0
	15s	13.69	17.50	9.31	1.5 : 1.9 : 1.0
Middle trapezius	120s	46.48	34.43	16.86	2.8 : 2.0 : 1.0
	60s	33.07	20.72	10.32	3.2 : 2.0 : 1.0
	30s	31.15	22.27	12.88	2.4 : 1.7 : 1.0
	15s	36.85	26.06	13.59	2.7 : 1.9 : 1.0
Upper trapezius	120s	41.88	37.95	14.37	2.9 : 2.6 : 1.0
	60s	31.97	27.51	12.25	2.6 : 2.2 : 1.0
	30s	31.72	27.72	12.34	2.6 : 2.2 : 1.0
	15s	32.94	28.78	12.66	2.6 : 2.3 : 1.0

The largest differences in activation between the tasks were identified for the middle deltoid (Figure 17; 10.8 : 7.1 : 1.0) and posterior deltoid (8.9 : 4.9 : 1.0). By comparison to other muscles, their low contribution during the neutral task influenced the magnitude of the ratios. Along with middle and posterior deltoid, large differences in activation were revealed between the two phases of the overhead task for middle trapezius (Figure 18; 2.8 : 2.0 : 1.0) and infraspinatus (2.9 : 2.0 : 1.0).

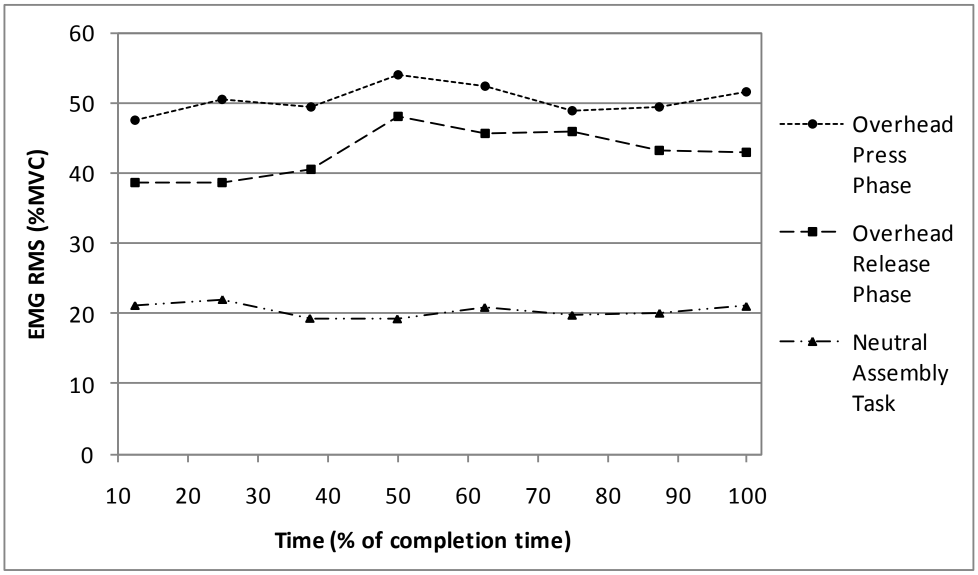


Figure 17: Comparison of activation between tasks for the middle deltoid

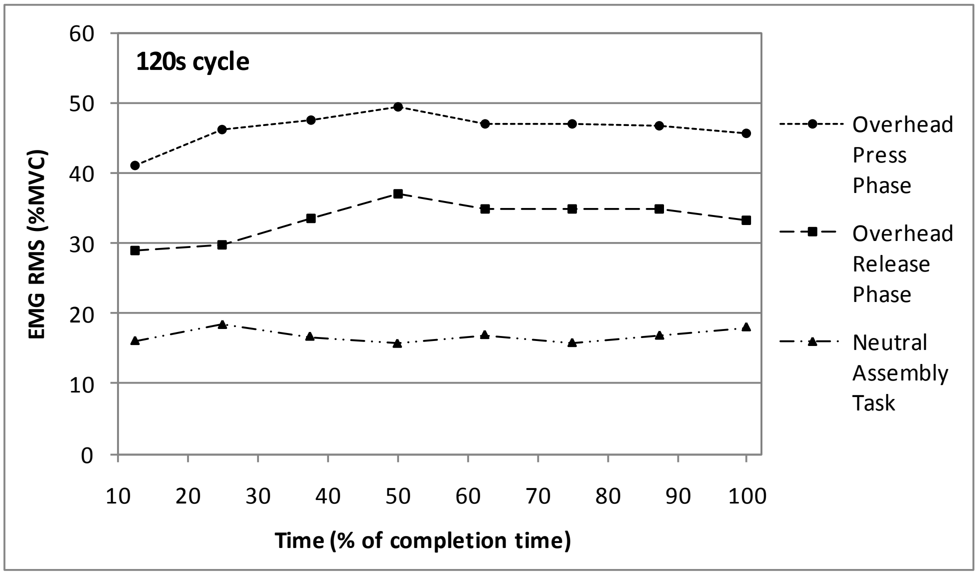


Figure 18: Comparison of activation between tasks for the middle trapezius

Muscles having similar levels of activation between the two phases of the overhead task included upper trapezius (Figure 19; 2.9 : 2.6 : 1.0), supraspinatus (2.5 : 2.2 : 1.0) and anterior deltoid (4.7 : 4.3 : 1.0). Compared to upper trapezius and supraspinatus, lower levels of activation were recorded for anterior deltoid during the neutral task.

A few muscles did not follow the same trend in activation levels across tasks as the previously described muscles. The release phase of the overhead task was the task requiring the highest level of activation for pectoralis major (Figure 20; 0.9 : 1.1 : 1.0) and lower trapezius (1.1 : 1.6 : 1.0). This trend was more evident for lower trapezius, but levels of activation were very low (<18%MVC). Very similar, low levels of activation (<21%MVC) were recorded across tasks for pectoralis major.

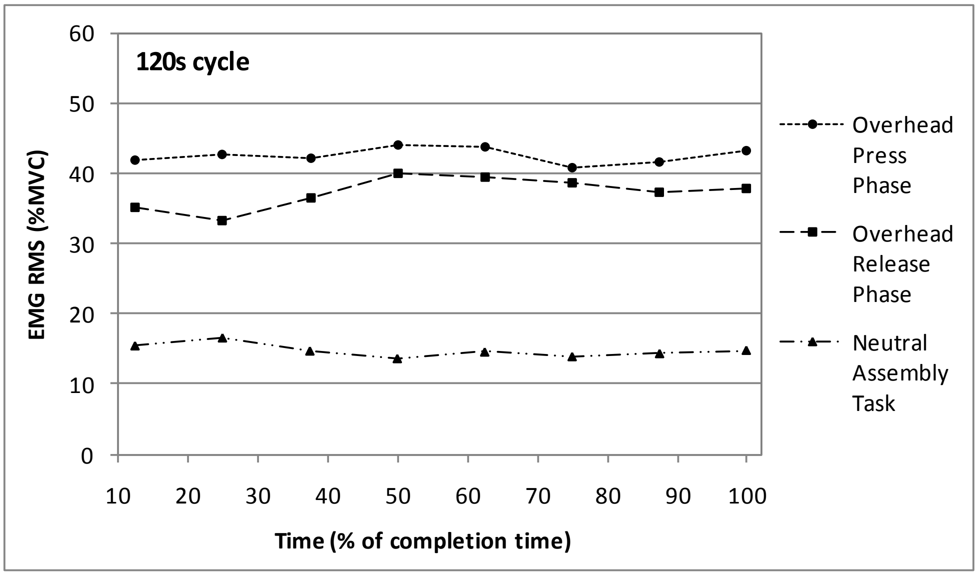


Figure 19: Comparison of activation between tasks for the upper trapezius

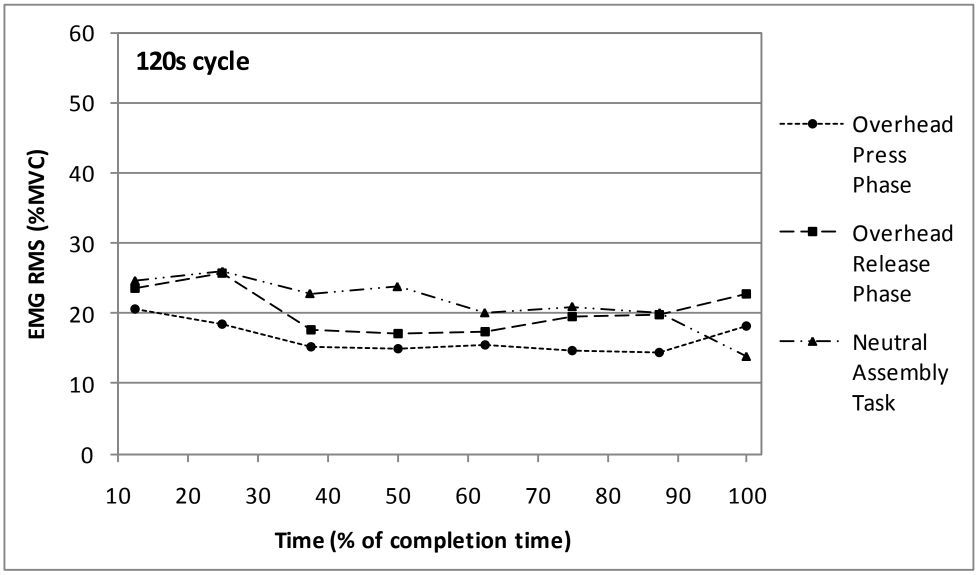


Figure 20: Comparison of activation between tasks for the pectoralis major

4.3 EMG measures over time

Assessment of EMG for the fatigue analysis was based on the press phase of the overhead task. Interpretation of several statistical tests performed on median power frequency and root mean square amplitude guided analysis of the effect of cycle time condition over time. Prior to evaluating differences in EMG measures due to cycle time, separate examination of each condition was completed to determine the effect of time on EMG measures. For conditions eliciting a significant increase in RMS amplitude or decrease in MdPF over time, the largest significant difference (%) from baseline was reported (Table 6). The RMS amplitude of five muscles increased and the median power frequency of six muscles decreased over time in at least one condition. Muscles experiencing significant changes in both EMG measures over time for the same condition were: supraspinatus, middle and upper trapezius. For these muscles, only the 120s condition elicited changes in both EMG measures over time.

The primary analysis assessed differences in EMG measures across conditions over time. In the initial analysis, if EMG measures in all conditions were not significantly affected by time, any differences due to cycle time condition would not be considered. Significant interactions between condition and time existed for the RMS amplitude of middle and posterior deltoid. However, examination of median power frequency of all muscles tested did not identify significant differences in conditions over time.

Table 6: Largest significant difference in average median power frequency and average root mean square amplitude from baseline for each condition (time of occurrence expressed as % of completion time and denoted below value)

	Largest significant difference from baseline (%)							
	MdPF				RMS			
	120s	60s	30s	15s	120s	60s	30s	15s
Anterior deltoid	***-7.85*** (0 – 50%)	***-8.90*** (0 – 100%)	-	-	-	-	-	-
Middle deltoid	-	-	-	-	***75.74*** (0 – 87.5%)	***40.89*** (0 – 50%)	-	-
Posterior deltoid	-	***-9.15*** (0 – 62.5%)	-	-	***118.59*** (0 – 75%)	-	-	-
Infraspinatus	***-11.95*** (0 – 62.5%)	-	-	-	-	-	-	-
Supraspinatus	***-8.63*** (0 – 62.5%)	***-7.91*** (0 – 100%)	***-11.30*** (0 – 87.5%)	***-9.16*** (0 – 75%)	***34.38*** (0 – 50%)	-	-	-
Middle trapezius	***-7.24*** (0 – 62.5%)	-	***-9.03*** (0 – 62.5%)	-	***76.27*** (0 – 50%)	***40.33*** (0 – 50%)	-	***49.55*** (0 – 50%)
Upper trapezius	***-8.01*** (0 – 87.5%)	***-7.00*** (0 – 100%)	***-7.70*** (0 – 87.5%)	***-8.02*** (0 – 75%)	***38.05*** (0 – 50%)	-	-	-

4.3.1 Amplitude analysis – root mean square

Amplitude analysis of certain muscles over time revealed differences in the magnitude of RMS increase between conditions. RMS amplitude was different between conditions over time for middle deltoid (Figure 21, F[24,189]=3.10, p<0.0001) and posterior deltoid (Figure 23, F[24,189]=2.52, p=0.0003). For middle deltoid, the 120s condition induced higher RMS amplitudes than other conditions from 50% to 100% of completion time. Over the last half of the protocol, the average RMS amplitude during the 120s condition was 72% higher than baseline and higher than the 60s, 30s and 15s conditions by 40%, 59% and 38%, respectively. Post hoc analysis of the main effect of condition confirmed that the 120s condition had higher average RMS amplitude compared to all other cycle times for middle deltoid (Figure 22). Similar results were found when assessing posterior deltoid; larger RMS amplitudes existed during the 120s condition from 87.5% to 100% of completion time. Over this time period, average RMS amplitude for the 120s condition exceeded baseline values by 112% and was higher than the 60s, 30s and 15s conditions by 75%, 95% and 65%, respectively. Analysis of the main effect of condition indicated that the 60s condition was not significantly different than the 120s condition (Figure 24). Examining each condition over time, both muscles had a significant increase in RMS during the 120s condition, but only middle deltoid RMS amplitude significantly increased over the 60s condition (F[8,64]=4.86, p=0.0001).

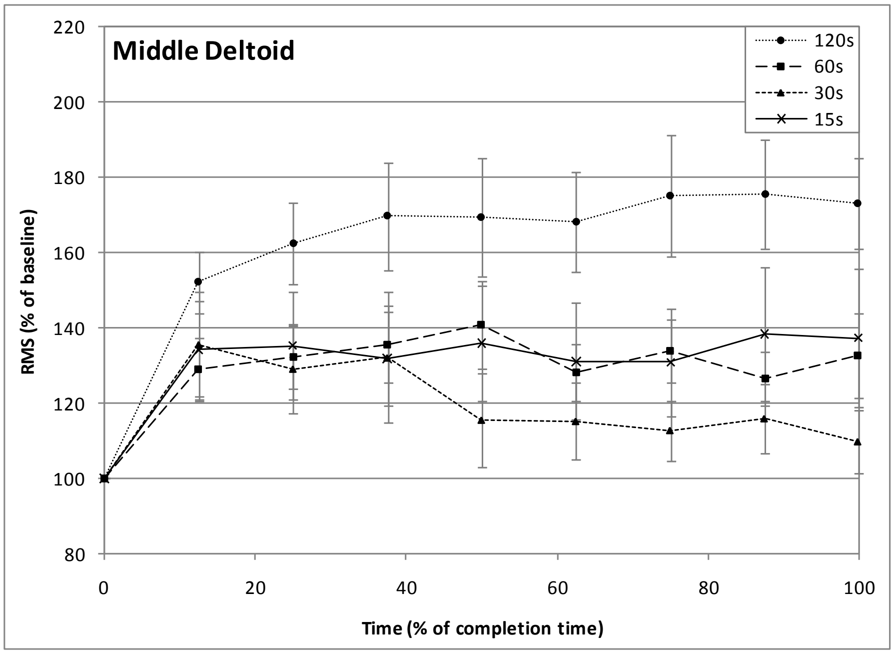


Figure 21: Average root mean square amplitude of middle deltoid over time for each cycle time

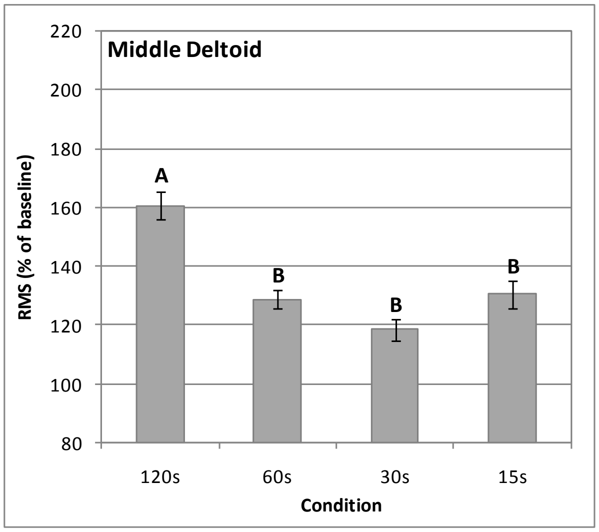


Figure 22: Average root mean square amplitude of middle deltoid for each cycle time

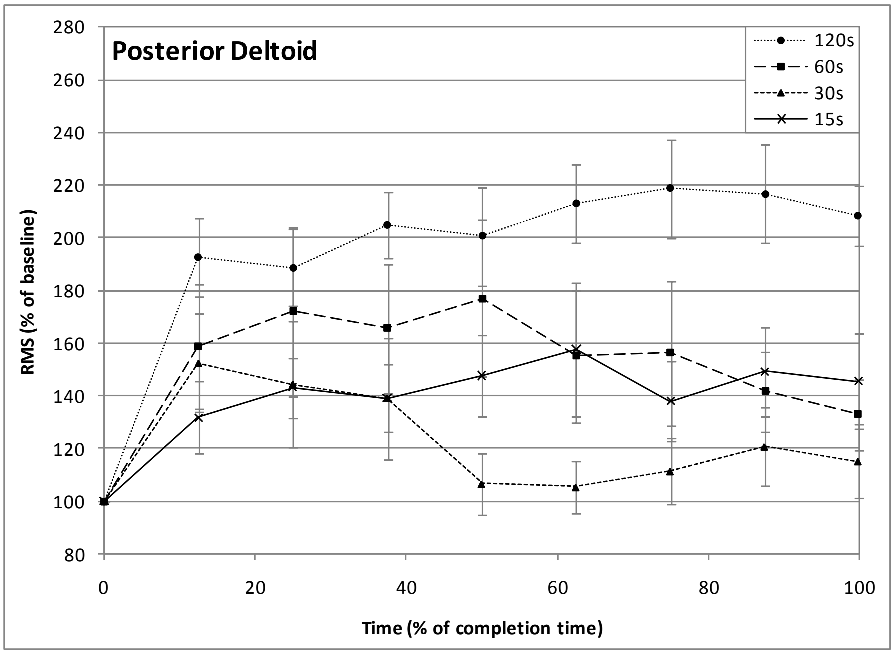


Figure 23: Average root mean square amplitude of posterior deltoid over time for each cycle time

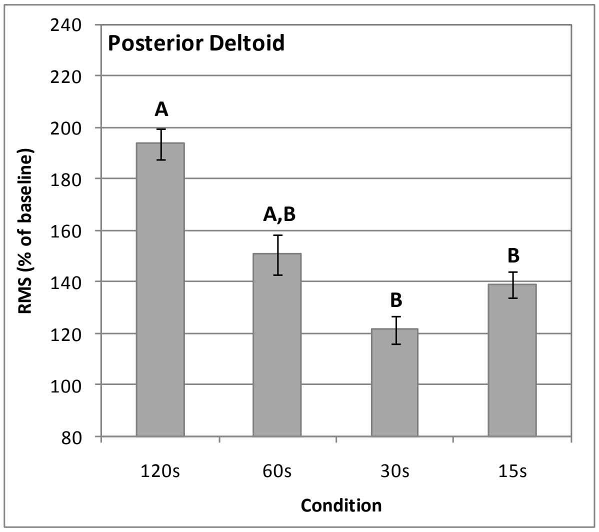


Figure 24: Average root mean square amplitude of posterior deltoid for each cycle time

Muscles experiencing a significant increase in average RMS amplitude over time included: middle trapezius (Figure 25), upper trapezius (Figure 26) and supraspinatus (Figure 27Figure 27). For these muscles, conditions were not statistically different over time. However, the effect sizes of condition over time on RMS amplitudes of these muscles were large (middle trapezius: $\eta_p^2 = 0.22$; upper trapezius: $\eta_p^2=0.16$; supraspinatus: $\eta_p^2=0.16$). Assessment of conditions separately over time revealed that the 120s condition induced a significant increase in RMS amplitude (middle trapezius: F[8,61]=8.11, $p<0.0001$; upper trapezius: F[8,61]=3.92, $p=0.0009$; supraspinatus: F[8,61]=2.47, $p=0.0215$). This was the only cycle time that significantly increased RMS in supraspinatus and upper trapezius. RMS amplitude of middle trapezius also increased over time for the 60s (F[8,64]=3.64, $p=0.0015$) and 15s condition (F[8,64]=4.90, $p=0.0012$).

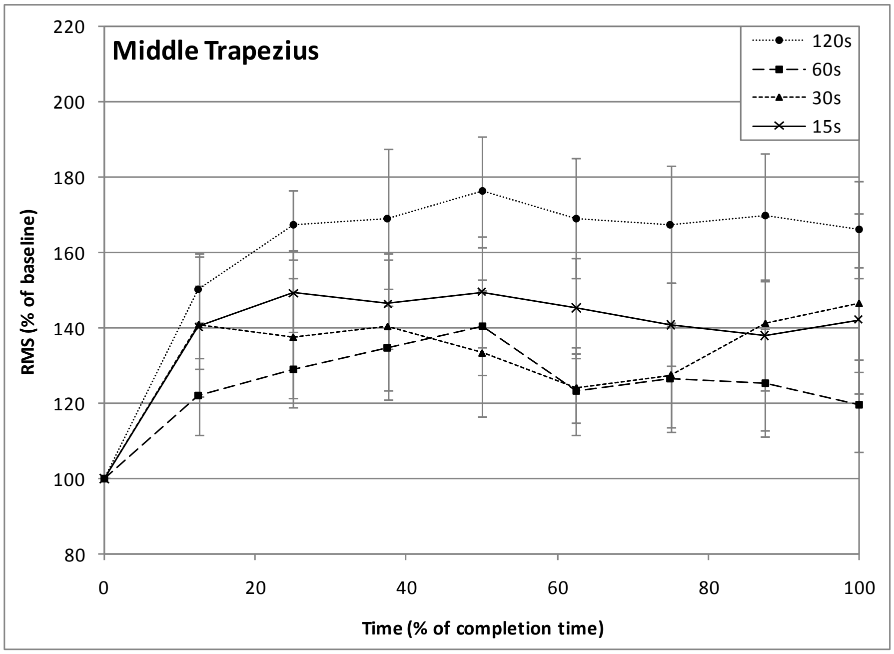


Figure 25: Average root mean square amplitude of middle trapezius over time for each cycle time

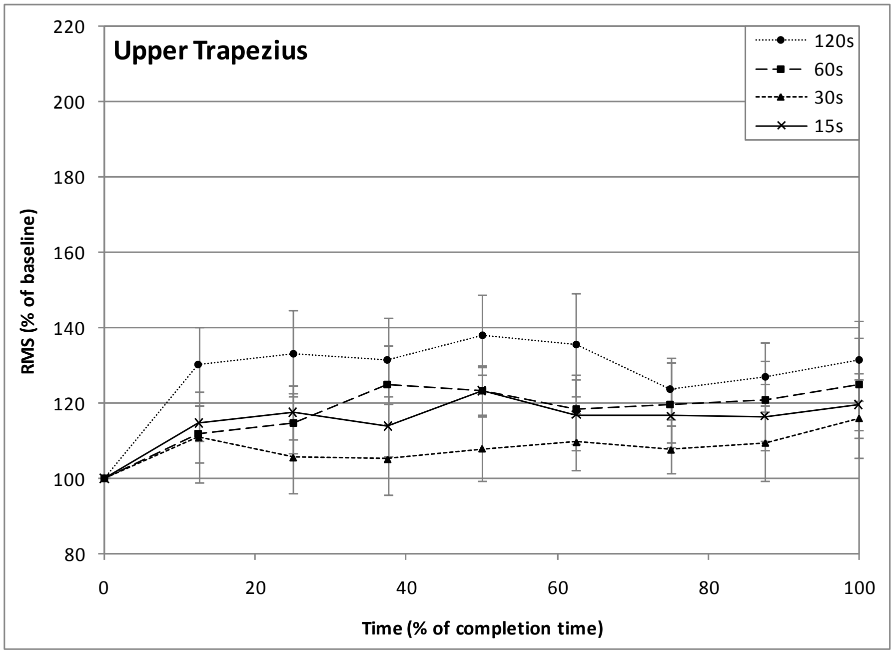


Figure 26: Average root mean square amplitude of upper trapezius over time for each cycle time

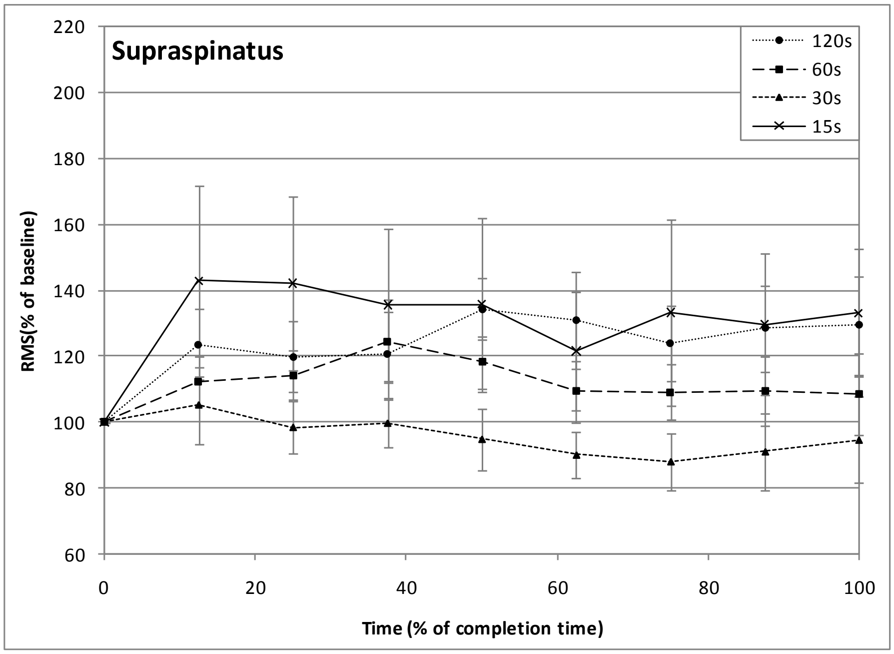


Figure 27: Average root mean square amplitude of supraspinatus over time for each cycle time

A few muscles maintained RMS amplitide close to baseline values over time and across conditions. These muscles included: anterior deltoid (Figure 28) and infraspinatus (Figure 29). For both muscles, assessment of conditions separately over time revealed that all conditions remained significantly the same as baseline RMS amplitude.

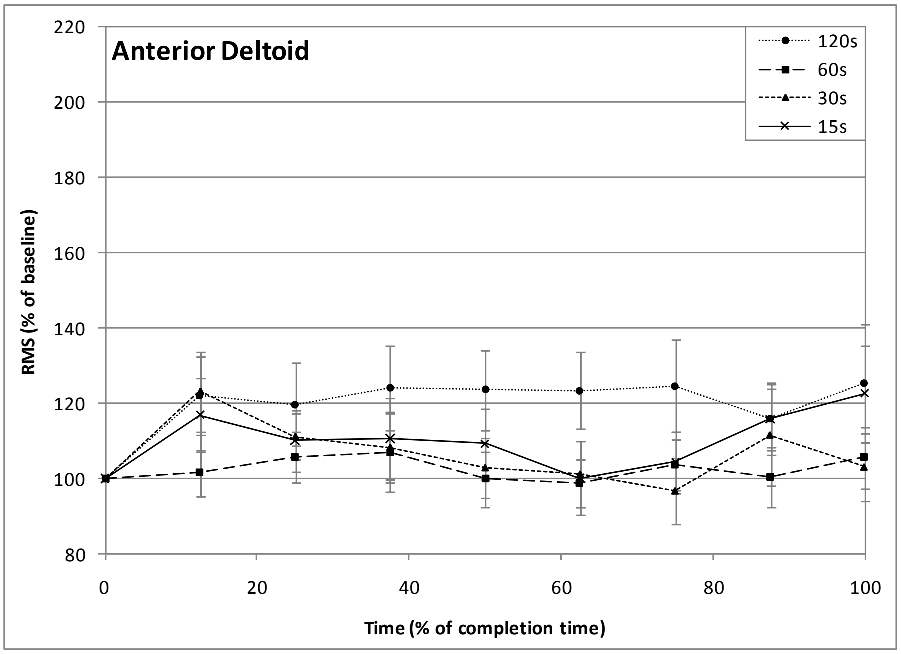


Figure 28: Average root mean square amplitude of anterior deltoid over time for each cycle time

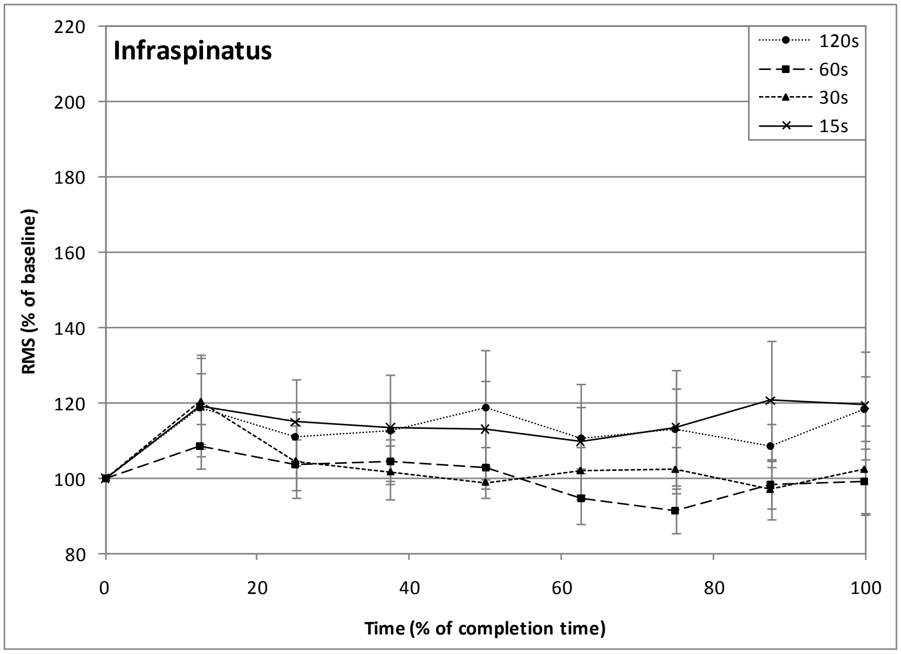


Figure 29: Average root mean square amplitude of infraspinatus over time for each cycle time

4.3.2 Spectral analysis – median power frequency

Analysis of the effect of condition and time was performed on the average median power frequency of each muscle. Over time, MdPF of all muscles tested was not statistically different between cycle time conditions. Averaged over conditions, significant decreases in MdPF over time were identified for upper trapezius (F[8,64]=7.66, p<0.0001), supraspinatus (F[8,64]=9.38, p<0.0001), middle trapezius (F[8,64]=10.70, p<0.0001), anterior deltoid (F[8,64]=3.92, p=0.0008) and infraspinatus (F[8,64]=5.34, p<0.0001).

Cycle time conditions were analyzed independently to detect which conditions elicited a significant decrease in MdPF over time. Across all conditions, the two muscles demonstrating signs of fatigue through significant decreases in MdPF were upper trapezius (Figure 30) and supraspinatus (Figure 31). These muscles experienced significant decreases in MdPF across all conditions (Table 6). For upper trapezius, the largest significant decrease in MdPF compared to baseline ranged from 7.00% to 8.02% across cycle time conditions. The range of largest significant decrease in supraspinatus MdPF compared to baseline across conditions was 7.91% to 11.30%.

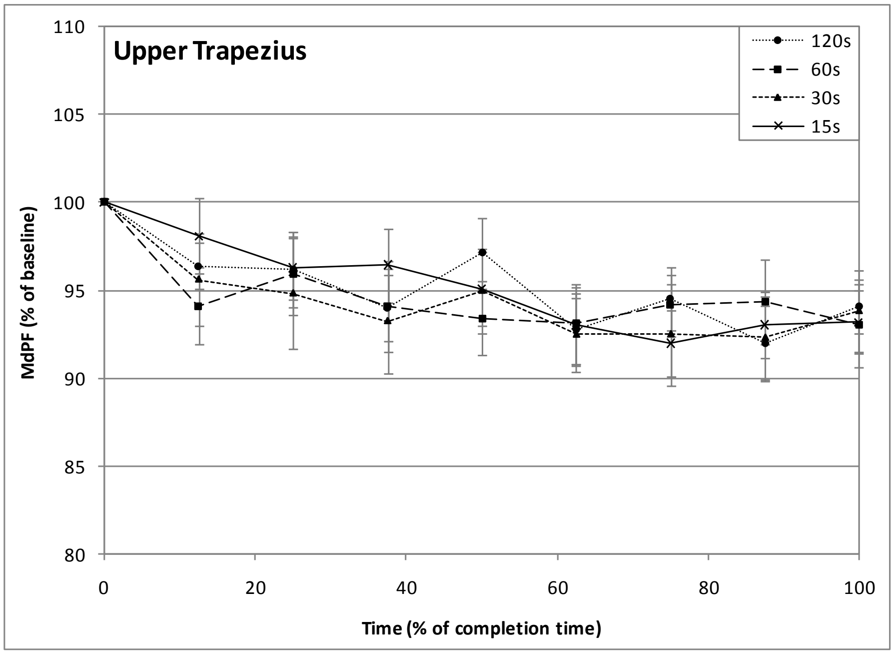


Figure 30: Average median power frequency of upper trapezius over time for each cycle time

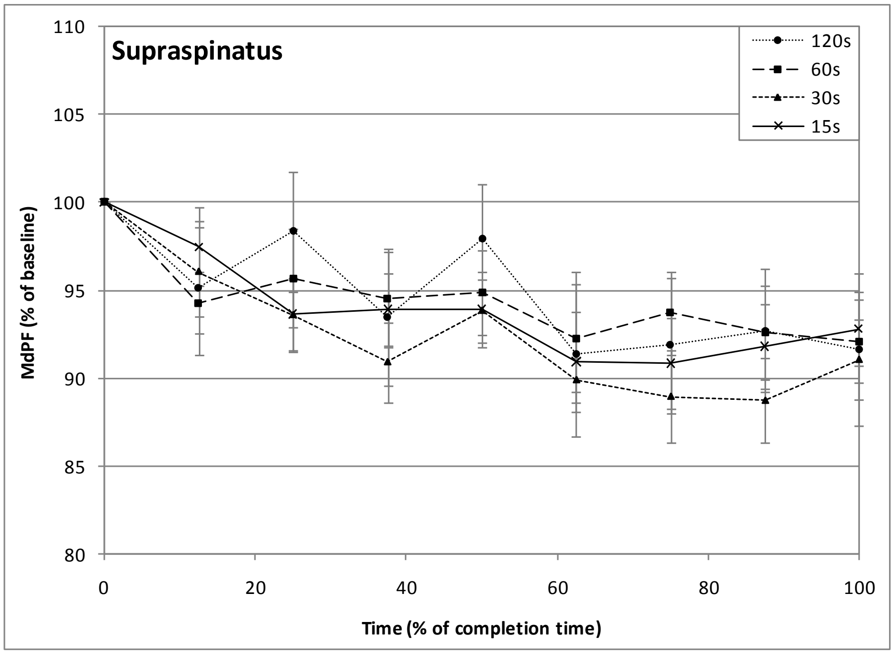


Figure 31: Average median power frequency of supraspinatus over time for each cycle time

Other muscles experiencing significant decreases in MdPF for one or two conditions included: middle trapezius (Figure 32), anterior deltoid (Figure 33), infraspinatus (Figure 34) and posterior deltoid (Figure 35). Significant decreases in MdPF of anterior deltoid were detected for the 120s (F[8,61]=2.32, p=0.0306) and 60s (F[8,64]=4.58, p=0.0002) conditions. A moderate to large effect (η_p^2=0.12) of condition over time on the MdPF of anterior deltoid was also identified. Over the 120s (F[8,61]=3.23, p=0.0039) and 30s (F[8,64]=4.49, p=0.0002) conditions, the MdPF of middle trapezius decreased significantly. After the Huynh-Feldt adjustment was applied to correct for non-sphericity of the variance, decrease in MdPF of middle trapezius in the 60s condition became insignificant. However, the effect size of time on MdPF was large (η_p^2=0.23). The MdPF of infraspinatus during the 120s condition decreased significantly over time (F[8,61)=3.97, p=0.0008).

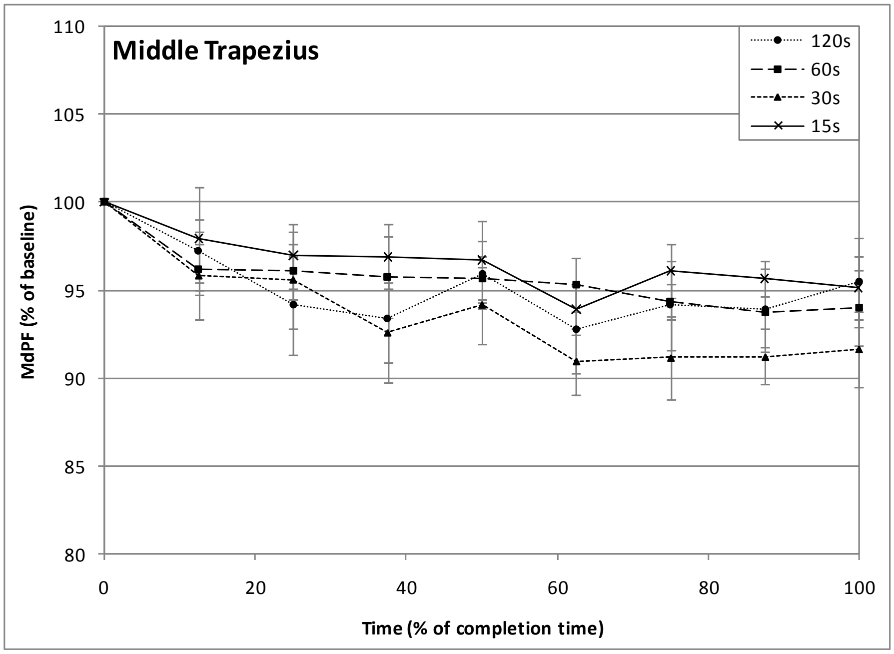


Figure 32: Average median power frequency of middle trapezius over time for each cycle time

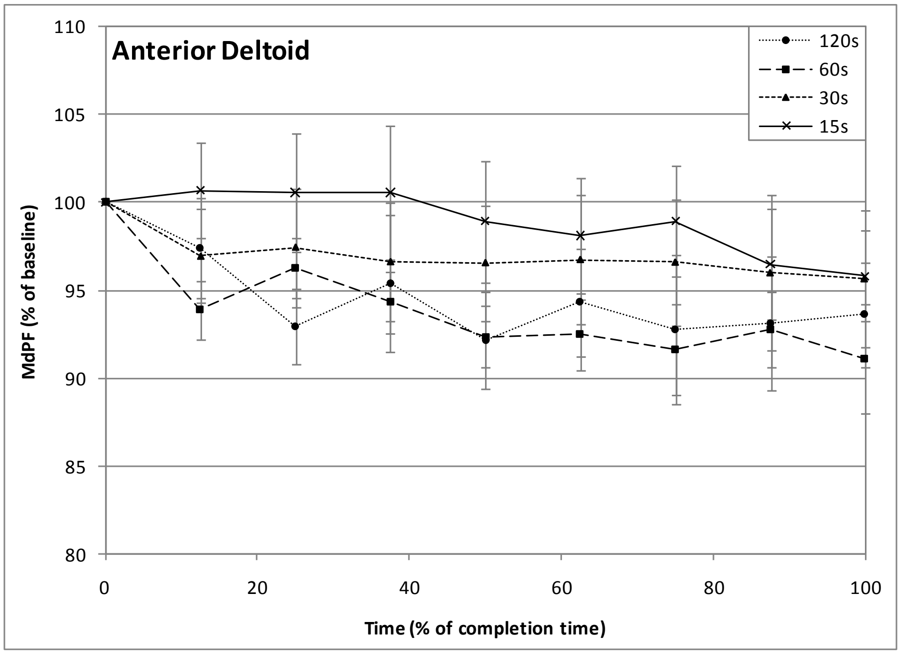


Figure 33: Average median power frequency of anterior deltoid over time for each cycle time

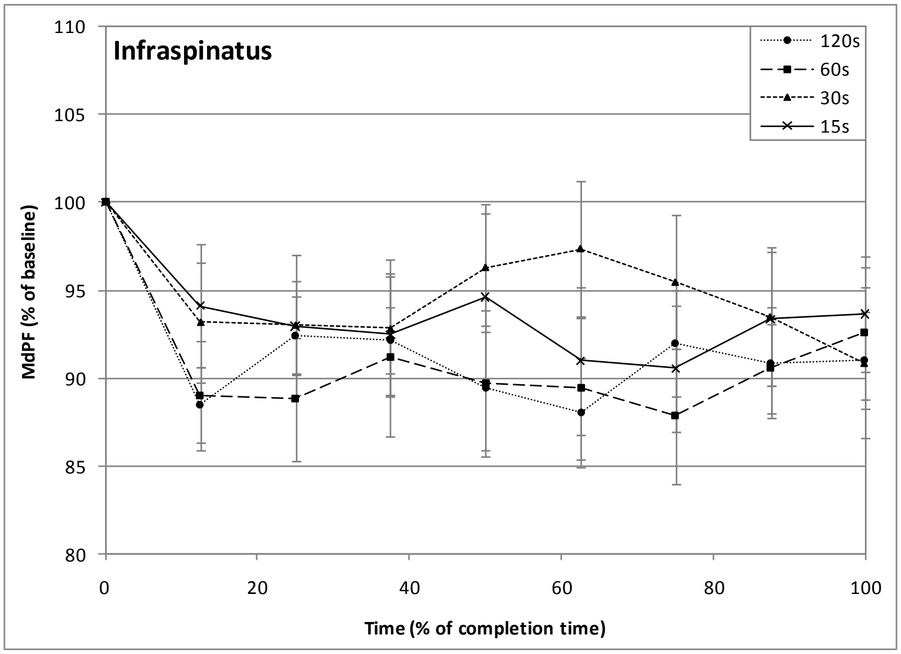


Figure 34: Average median power frequency of infraspinatus over time for each cycle time

Examination of certain muscles over time revealed maintenance and in some conditions increases in median power frequency. Although average MdPF of the posterior deltoid significantly decreased over time during the 60s condition (F[8,64]=4.08, p=0.0006), average MdPF of all other conditions remained close to baseline values. There was no significant decrease in average MdPF over time for the middle deltoid (Figure 36). Comparing baseline values to the last time point revealed that all conditions had an overall increase in average MdPF. However, for posterior deltoid, only the 30s condition increased over time.

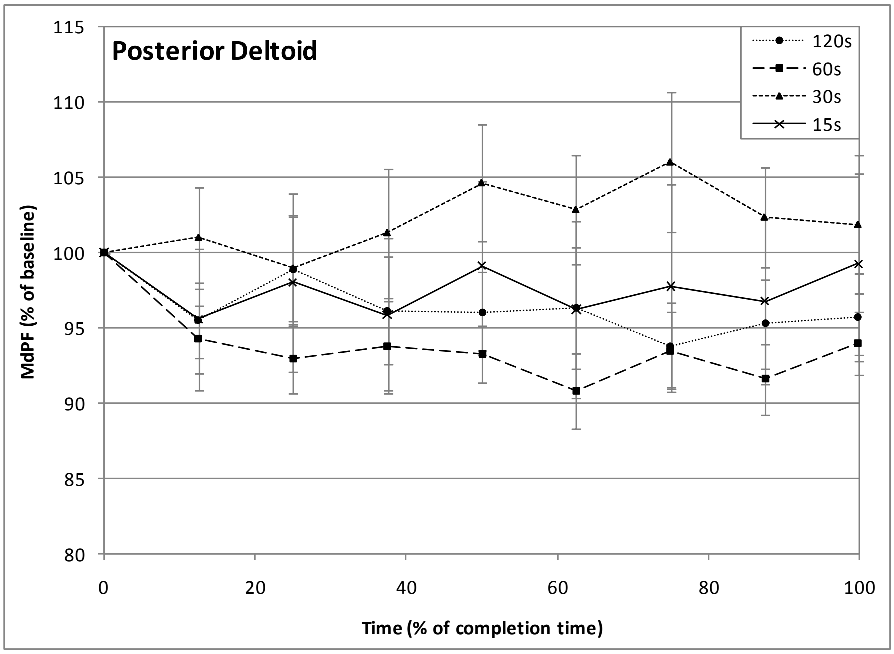


Figure 35: Average median power frequency of posterior deltoid over time for each cycle time

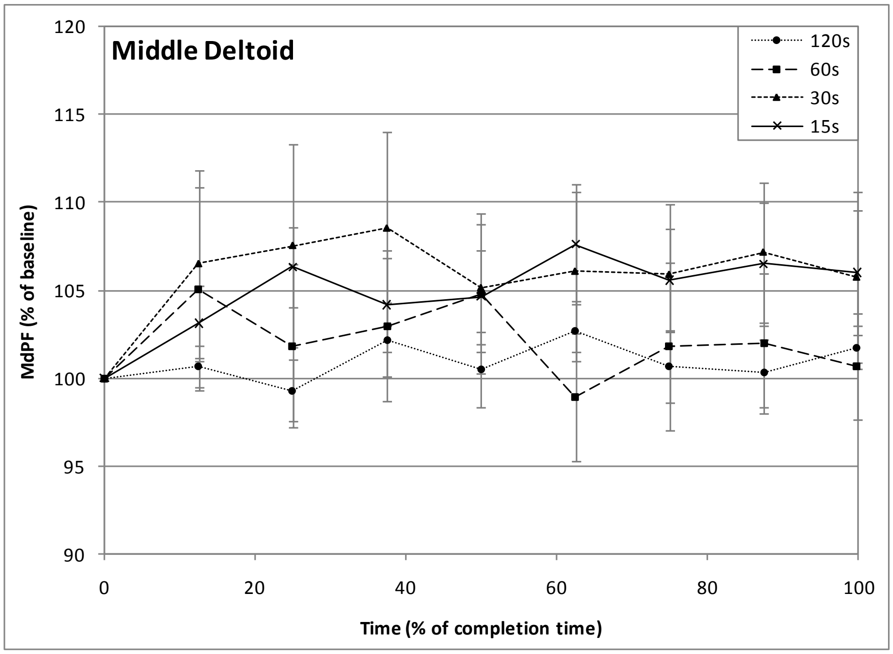


Figure 36: Average median power frequency of middle deltoid over time for each cycle time

4.4 Rating of perceived exertion over time

Subjective differences due to cycle time were assessed through perception of shoulder exertion which was quantified using the Borg CR-10 scale. In every condition, rating of perceived exertion increased over time, but the rate of increase was statistically the same across conditions (F[3,24]=3.64, p=0.0556). For visual comparison of each participant within each condition, slopes were extrapolated to the 3 hour mark (Figure 37). However, the effect size of cycle time condition on the rate of perceived exertion over time was large (η_p^2=0.31).

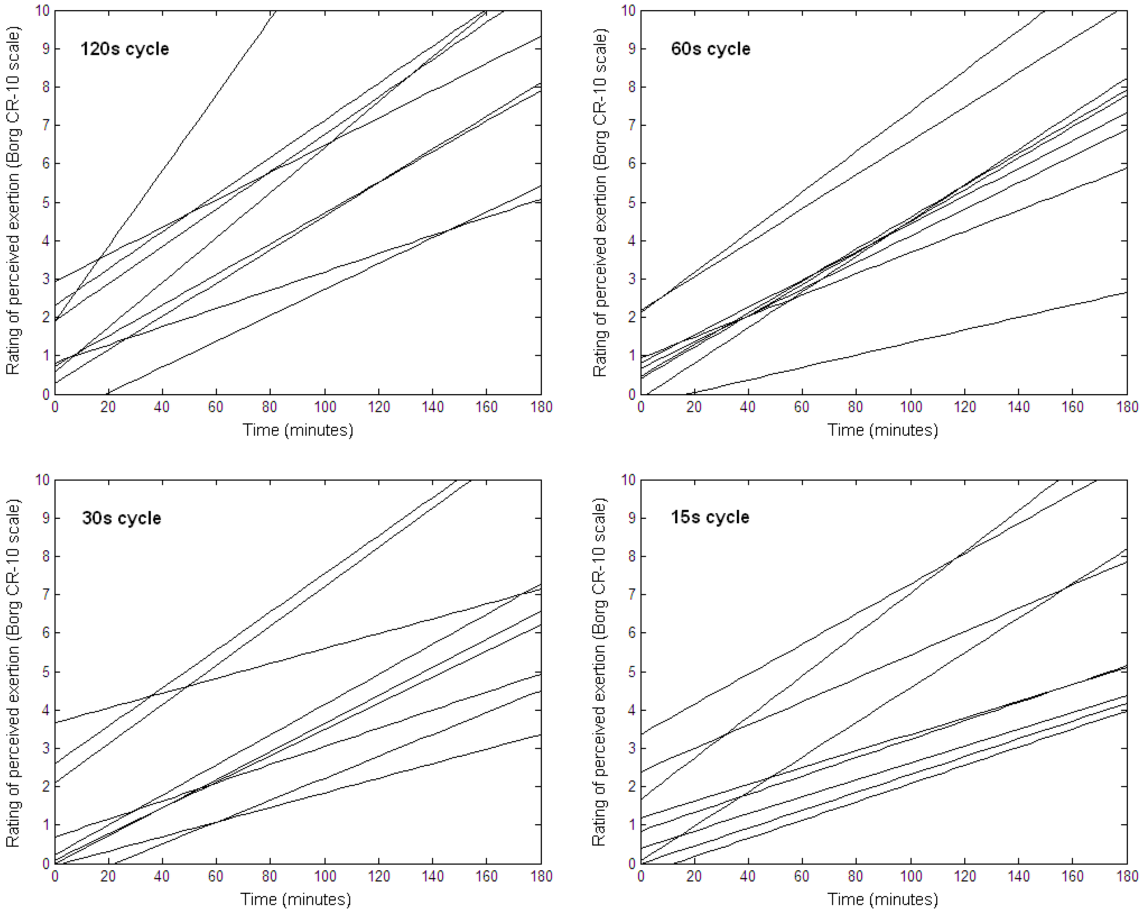


Figure 37: Comparison of extrapolated slopes for rating of perceived exertion over time for each condition

Table 7: Results of one-way repeated measures ANOVA assessing the slope of rating of perceived exertion over time

Condition	Mean	F Ratio	P Value	η_p^2
120s	0.0479	3.64	0.0556	0.31
60s	0.0378			
30s	0.0335			
15s	0.0315			

4.5 Static strength capability over time

Analysis of average static strength capability over time was used to detect physiological differences due to cycle time condition. For all conditions, there was an overall decrease in static strength capability over time (Figure 38). However, this decrease in static strength over time was statistically the same for all cycle time conditions (F[3,24]=2.91, p=0.0554). Although there was no statistical difference in the rate of strength decrease between conditions, a large effect size (η_p^2=0.27) of condition was identified.

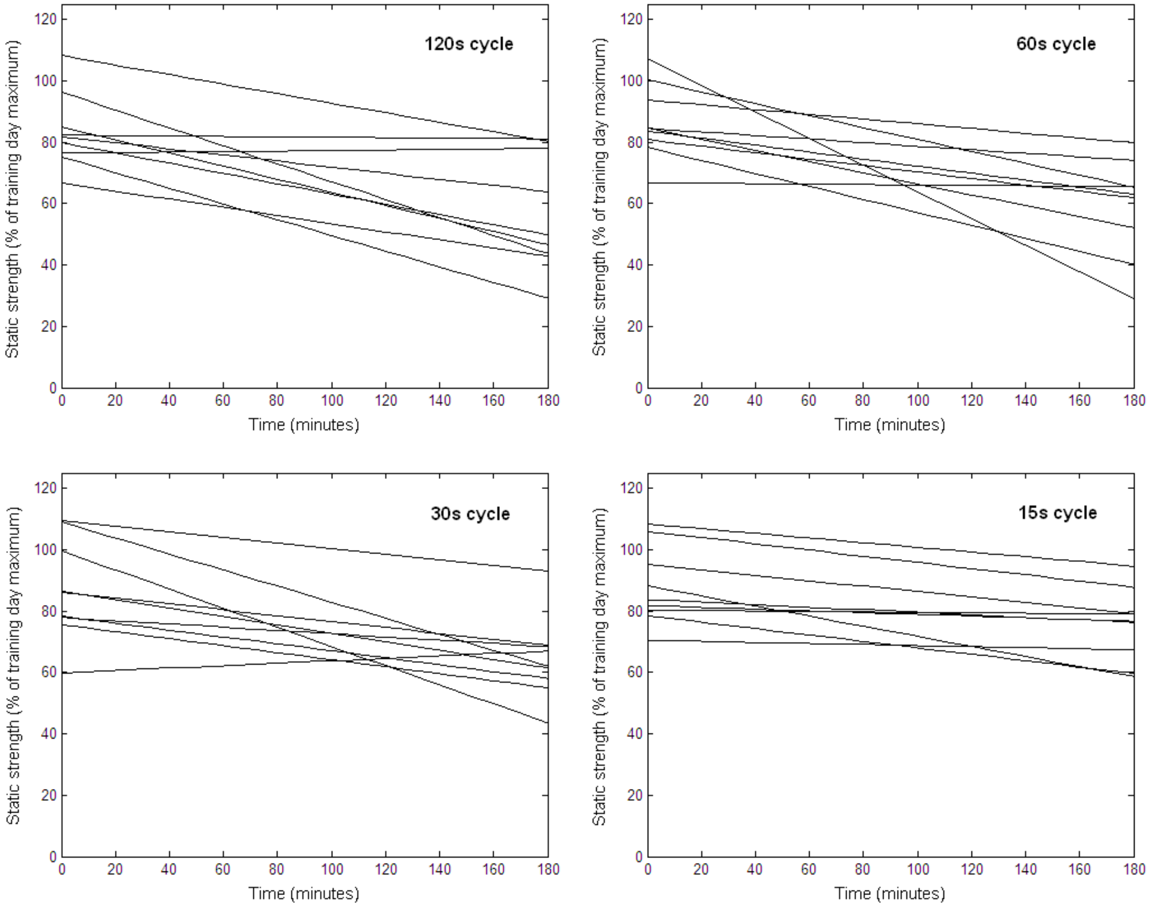


Figure 38: Comparison of extrapolated slopes for static strength over time for each condition

Table 8: Results of one-way repeated measures ANOVA assessing the slope of static strength over time

Condition	Mean	F Ratio	P Value	η_p^2
120s	-0.1460	2.91	0.0554	0.27
60s	-0.1535			
30s	-0.1265			
15s	-0.0697			

4.5.1 Static strength variability

Maximum static strength of each participant for every session was reported to assess the day to day variation within participants and variability between participants. Descriptive statistics were used to summarize findings for each participant (

Table 9). Standard deviations within participants ranged from 6% (P04) to 15% (P01) of average static strength across sessions. To describe variability of average static strength across participants, maximum static strength values of all sessions were averaged and normalized to the maximum static strength achieved on the training session (Figure 39). Average maximum static strength ranged between 79% (P09) and 112% (P05).

Table 9: Maximum static strength achieved in each session for all participants

Session	Maximum static strength (N)								
	P01	P02	P03	P04	P05	P06	P07	P08	P09
Training	287.09	239.94	191.62	222.84	247.72	277.82	280.64	211.31	207.69
120s	213.80	292.24	180.97	192.81	288.84	239.62	230.24	176.77	152.63
60s	318.20	263.04	163.87	195.20	266.71	278.18	220.95	182.65	151.10
30s	309.14	287.31	177.67	205.54	270.72	247.36	217.11	183.70	148.91
15s	263.84	246.55	207.62	211.17	307.47	252.23	263.67	199.58	161.67
Average	**278.41**	**265.82**	**184.35**	**205.51**	**276.29**	**259.04**	**242.52**	**190.80**	**164.40**
SD	*41.80*	*23.50*	*16.35*	*12.25*	*22.74*	*17.88*	*28.12*	*14.24*	*24.68*

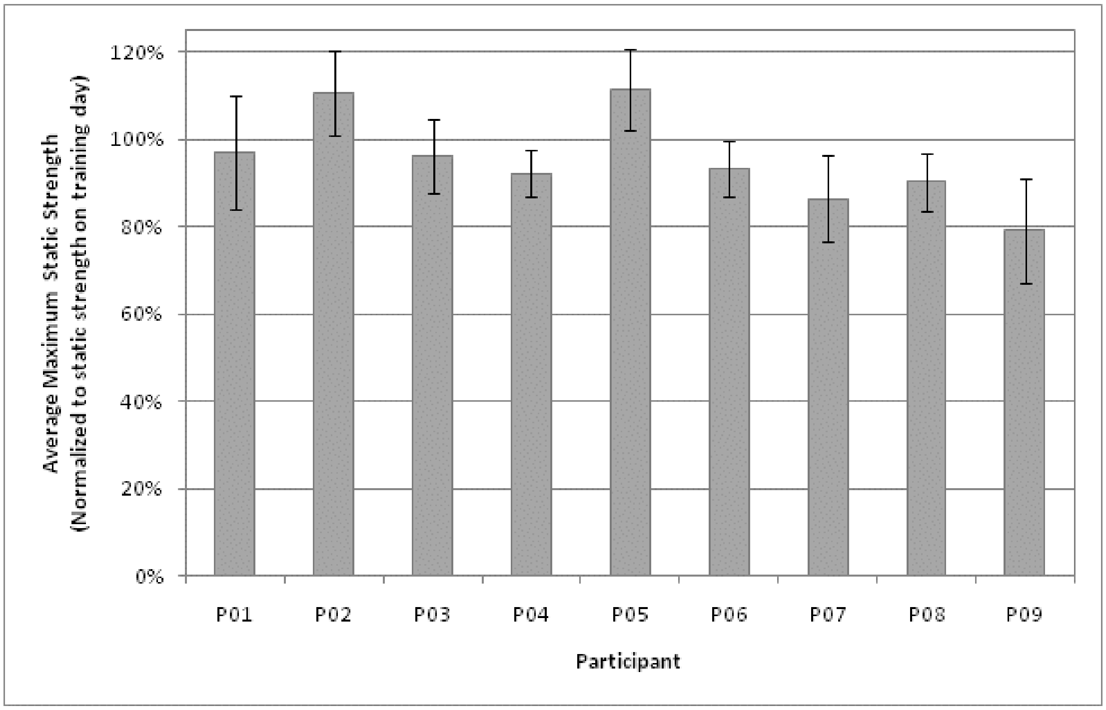


Figure 39: Average maximum static strength values over all sessions and normalized to maximum static strength on training day

4.5.2 Effect of daily maximal static strength on fatigue measures

Large amounts of variation in maximal static strength from day to day occurred within participants. It is possible that differences in daily maximal static strength could have affected the rate of fatigue measures over time which would mask the effect of cycle time. For each condition, correlation was used to quantify the relationship between normalized daily maximal strength and slopes of fatigue measures (Table 10). Since all R^2 values were below 0.4, there is likely no or very small relationship between daily maximal static strength on dependant measures.

Table 10: Results of correlation analysis (R^2) from linear regression of normalized daily maximal strength and slopes of fatigue measures within each condition

Condition	Endurance Time	RPE	Static Strength

120s	0.39	0.17	0.02
60s	0.10	0.13	0.20
30s	0.10	0.13	0.38
15s	0.00	0.01	0.10

5.0 Discussion

The current study investigated whether different cycle times of work effected fatigue development during a prolonged intermittent overhead work task. Each condition was altered by changing the length of the cycle, and a constant workload was maintained by adjusting the frequency of cycles performed within a two minute block (Figure 5). Since the amount of overhead work performed in each block was the same across conditions, any significant differences revealed would be due to the change in cycle time. Five measures were used to monitor fatigue induced changes over time. These included endurance time, amplitude (RMS) and spectral (MdPF) measures calculated from surface EMG of nine shoulder muscles, static strength capability and rating of perceived exertion. Two measures revealed statistical differences due to cycle time condition. The condition involving the longest cycle time resulted in shorter average endurance time compared to the cycle time having the shortest cycle lengths. Also, higher RMS amplitudes were identified for the middle and posterior deltoid during the condition with the longest cycle times. Statistical differences due to cycle time were not detected for the MdPF of all muscles tested. However, moderate to large effect sizes of condition for several muscles support the prediction that increased statistical power may reveal differences. Based on the results of the study, more convincing evidence of the effect of cycle time on fatigue development is required before speculating about its effectiveness as a work organizational method in the design of overhead work.

5.1 Addressing hypotheses

5.1.1 Endurance time would be longer for shorter cycle times

This hypothesis was supported since the condition with the shortest cycle time of overhead work appeared to be less fatiguing than the longest cycle time. Average endurance time was 34 minutes longer for the 15s condition than the 120s condition. The 15s condition involved performing the overhead work over 6 second intervals every task rotation compared to a 48 second bout of work in the 120s condition. A few studies investigating the fatigue response for intermittent static arm exercise protocols reported similar results. In 1993, Mathiassen revealed that upper arm elevations with shorter cycles (10s vs. 60s) resulted in a longer median endurance time of 15 minutes. Similarly, Iridiastadi and Nussbaum (2006a) identified that the shorter cycle time (34s vs. 166s) increased endurance time by 13 minutes for the highest contraction level and duty cycle tested. However, a significant effect of endurance time was not found since differences were not as pronounced at lower duty cycles and the protocol extended for a maximum of only one hour (Iridiastadi and Nussbaum, 2006a).

Contradicting results suggest that shorter cycle times are more fatiguing. Garg and colleagues (2006) found shorter cycle times elicited shorter psychophysical estimates of endurance time. The 2006 study was different than the current study in that a hand tool was constantly held while raising and lowering to and from the overhead position. This extra weight increased workload at the shoulder, and the faster positioning required with shorter cycle times consequently increased the rate of muscular fatigue and decreased the psychophysical estimate of endurance time (Garg et al., 2006). However, suspending the hand tool (current study), supporting the postural load of the extended upper extremity (Mathiassen, 1993) and removing postural load by placing participants in a supine posture (Iridiastadi and Nussbaum, 2006a), produced opposite results. This suggests that the effect of cycle time on endurance time for overhead work is dependent on the static and overall workload at the shoulder.

Suspending hand tools used in overhead work tasks have previously been suggested as an intervention intended to reduce loading on the shoulder (Albers et al., 2005). By removing the weight of the tool, the workload at the shoulder would be reduced and therefore requires less muscle force to perform the task. Reducing muscular demand over time delays the onset of muscle fatigue which allows workers to perform tasks for longer periods of time. Therefore, removing hand tool weight is predicted to be an effective intervention in delaying the development of fatigue and increasing endurance time for overhead tasks.

Although differences in endurance time existed between conditions, other factors should be considered before making conclusions. The measure of endurance time does not give insight into physiological changes over time (Mathiassen and Winkel, 1992). Therefore, interpretation of physiological and subjective fatigue measures over time is necessary in making recommendations for the design of work.

5.1.2 Shorter cycle times would result in smaller increases in EMG amplitude over time

Differences in cycle time conditions over time existed for the RMS amplitudes of two muscles: middle and posterior deltoid. For both muscles, the hypothesis was partially supported. The condition having the longest cycle time resulted in RMS amplitudes that were approximately 26% (middle deltoid) and 34% (posterior deltoid) higher than all other cycle times. Performing the overhead work in two intervals of 24s rather than one interval of 48s was sufficient in significantly reducing the magnitude of RMS increase over time for middle and posterior deltoid. Although the longest cycle time was the only condition significantly higher than the others, RMS does not appear to decrease linearly with cycle time. This relationship was identified for the main effect of condition of middle and posterior deltoid. It was predicted that shorter cycle times would reduce fatigue effects, however, the 30s cycle time condition produced the lowest level of RMS. As cycle times are reduced, the amount of active rest during the neutral task decreases. Through EMG gap analysis, Moore (2000) identified that very short cycles (<6s) did not allow sufficient rest for working muscles. Therefore, higher levels of RMS amplitude of middle and posterior deltoid during the shortest cycle are likely a result of fatigue due to insufficient rest during the 9s bouts of neutral assembly.

Since higher levels of RMS were detected for the longer cycle times, fatigue of the two deltoid muscles likely contributed to shorter endurance times. Upper arm elevation in the scapular plane involves activation of the anterior and middle portion of the deltoid in order to abduct the glenohumeral joint while elevating the scapula (Shevlin et al., 1969). The intermittency of the press and release phases of the overhead task resulted in slight raising and lowering of the glenohumeral joint. Across all conditions, activation of the middle deltoid was consistently highest (38%MVC on average) compared to other muscles during the press phase of the overhead task. However, large discrepancies in activation were revealed for all conditions when analyzing activation ratios (10:7:1 on average) between the two phases of overhead work. The differences in activation between the two tasks indicate middle deltoid's large role in generating force for the overhead press once positioned in the overhead posture. Significant differences in RMS amplitude of posterior deltoid were identified between conditions. Similarly to middle deltoid, differences in activation levels between the press and release phases were high producing an average activation ratio of 8:5:1 across conditions. Although this indicates the muscle's contribution to force production during the press phase, it was the lowest activated muscle (25%MVC on average) out of the seven selected for fatigue analysis. Performing the overhead work for long cycles likely did not permit sufficient rest in these muscles resulting in higher RMS amplitudes due to recruitment of more motor units (Edwards and Lippold, 1956; Basmajian and De Luca, 1985), increased excitation rate (Bigland-Richie et al., 1986) and synchronization of motor units (Lippold et al., 1960). Results of a study investigating the fatigue response of an intermittent overhead tapping task also revealed that RMS of the anterior and middle deltoid was higher than the upper trapezius and infraspinatus across all conditions (Nussbaum et al., 2001). Also, at the highest contraction level and duty cycle, the rate of RMS increase for middle deltoid during longer cycles (166s) of arm abductions was 0.26%/min higher than shorter cycles (34s) (Iridiastadi and Nussbaum, 2006a).

Examining each condition separately identified muscles that increased in RMS amplitude for specific conditions. The longest cycle time induced a RMS increase of 76% for middle trapezius which was the same magnitude as middle deltoid under the same condition. However, the conditions with shorter cycle times also influenced significant increases (60s: 40% and 15s: 50%) in RMS of middle trapezius. Since the longest and shortest cycle lengths elicited largest significant differences of 76% and 50% from baseline RMS, this suggests that cycle time did not have a fatigue reducing effect on middle trapezius. For the condition with the longest cycle time, the RMS of supraspinatus and upper trapezius significantly reached 34% and 38% above baseline values. Over time, all conditions for supraspinatus remained within 35% of each other, indicating that cycle time does not alter the amount of upper trapezius activation required to perform the overhead task. A similar effect was identified for supraspinatus with the exception of the 30s condition which decreased in RMS over time.

EMG amplitude of some muscles under certain conditions initially increased and then began to decrease over time. For middle and posterior deltoid, the 30s condition elicited an initial increase in RMS amplitude which was followed by a large decrease of 17% and 33%, respectively at 50% of completion time. Since the shoulder complex is an indeterminate system, this decrease over time may be due to the redistribution of forces through activation of synergistic muscles surrounding the shoulder (Palmerud et al., 1995; Jensen et al., 2000). Palmerud and colleagues (1998) discovered that voluntary relaxation of the upper trapezius while maintaining a static posture lead to redistribution of muscle activation to rhomboid major, middle trapezius and rhomboid minor. Since the activity of the rhomboids were not monitored in the current study, this hypothesis is plausible. However, this explanation would be more convincing if this pattern was observed across all conditions within a muscle.

5.1.3 Shorter cycle times would result in smaller decreases in EMG median power frequency over time

For all seven muscles examined, the hypothesis was unsupported since cycle time did not significantly affect the magnitude of MdPF decrease over time. However, analysis of MdPF decrease over time (independent of condition) revealed that longer cycle times tended to elicit a decrease in MdPF while shorter cycle times did not. Similarly, Iridiastadi and Nussbaum (2006b) reported that longer cycle times of intermittent arm abductions led to greater decreases in mean and median power frequency of the middle deltoid. However, Garg and colleagues (2002) only detected a linear decrease in mean power frequency of the middle deltoid for static exertions greater than 30%MVC. Since the mean load of the overhead task in the current study was lower than 30%MVC, it is possible that this factor reduced the ability to detect fatigue through spectral decline. Anterior deltoid decreased in MdPF by 8% and 9% from baseline for the two conditions having the longest cycle times (120s and 60s, respectively). For this muscle, cycle time condition had a moderate to large effect size (η_p^2=0.12) on MdPF over time. This suggests that with more statistical power, differences in MdPF between conditions over time may be revealed, supporting the findings of Iridiastadi and Nussbaum (2006b). Also, the condition with the second longest cycle time (60s) elicited a largest significant decrease of 9% in MdPF of posterior deltoid. It should also be noted that, although not statistically significant due to large amounts of variability, the 30s condition increased posterior deltoid MdPF over time. Since the average MdPF of the condition with the shortest cycle time remained close to baseline values over time, posterior deltoid may experience fatigue reducing effects through performance of overhead work in shorter cycles (15s – 30s). The large effect of condition (η_p^2=0.14) supports this hypothesis, and with more statistical power, changes in cycle time condition should reveal differences in the magnitude of MdPF.

Significant decreases in MdPF of the middle trapezius for the 120s (7%) and 30s (9%) conditions were identified. Although MdPF during the 60s condition did not significantly decrease over time, a large effect size of time (η_p^2=0.23) suggests that a significant reduction may be identified with more statistical power. Even though the condition with the shortest cycle time did not have a significant reduction in middle trapezius MdPF over time, the magnitude of decrease consistently remained within 1% of another condition. This suggests that cycle time does not affect the amount of MdPF decrease over time for the middle trapezius. This finding is in agreement with the results of RMS amplitude increase.

Supraspinatus and upper trapezius experienced significant reduction in MdPF ranging from 7% to 11% of baseline across all cycle time conditions. For these muscles, it appears that cycle time does not affect muscle fatigue progression through interpretation of MdPF and previous analysis of RMS. Due to its large role in performing overhead tasks, fatigue of the upper trapezius has previously been identified through spectral shifts in EMG (Herberts et al., 1980; Wiker et al., 1989; Nussbaum et al., 2001; Garg et al., 2002; Sood et al., 2007). It is not surprising that cycle time did not affect the development of fatigue in the upper trapezius because of its role in positioning the upper arm during overhead work tasks. It is primarily responsible for elevation of the lateral angle of the scapula (Wiedenbauer and Mortensen, 1952) and continuous activation would be required for maintenance of this posture. Also, as indicated by activation ratios, both phases of the overhead task were at similar levels for upper trapezius (2.9 : 2.6 : 1.0) and supraspinatus (2.5 : 2.2 : 1.0). This suggests that the upper trapezius and supraspinatus are largely involved in maintaining the overhead posture during the overhead task.

Through examining variability in mean power frequency of the unfatigued trapezius muscle, Oberg and colleagues (1990) concluded that a decrease of 8% from baseline would be an indication of muscle fatigue. In the current study, the majority of muscles which had a significant decrease in MdPF over time that exceeded this 8% threshold. However, there were five instances which had a significant decrease ranging between 7% - 8%.

5.1.4 Shorter cycle times would result in smaller increases in rating of perceived exertion over time

This hypothesis was unsupported since the perception of the level of shoulder exertion over time did not differ between conditions. Although the average rating of perceived exertion for the condition with the longest cycle time was steeper than all other conditions, this finding was not significant due to the variability of rating across participants. However, the effect size of condition on rating of perceived exertion over time was large. Having more statistical power may reveal that the longest cycle time for overhead work tasks significantly increases the rate of rating of perceived exertion over time.

Determining a statistically significant effect of cycle time condition on rating of perceived exertion may not be practically relevant. A psychophysical study determined maximal acceptable one-handed lifting frequencies and measured rating of perceived exertion at the end of the protocol (Garg and Saxena, 1982). The results revealed that acceptable lifting frequencies were associated with perceived exertion between ‘fairly light’ to ‘somewhat hard’ translating to a rating of 2 to 4 on the Borg CR-10 scale. Based on previous work, Garg and colleagues (2006) assumed that performing overhead work a rating of perceived exertion >4 would be associated with a high risk of adverse health effects. According to this threshold, the condition with the longest cycle times would be ‘unsafe’ at 62.5% of completion time compared to 75% of completion time for all other conditions. Although performing overhead work for the longest cycle time exceeded the threshold earlier, shorter cycle times were not far behind.

Cycle time may not have effected perceived exertion for multiple reasons. Firstly, rating of perceived exertion has been associated with physical workload at the shoulder (Dickerson et al., 2007). Since workload was not changed between conditions, it is not surprising that differences in rating of perceived exertion were not revealed. Also, effectiveness of subjective measures in detecting physiological changes due to low work intensity has been criticized (Mathiassen, 1993; Annett, 2002). Based on the current findings, recommendations for the organization of overhead tasks through changes in cycle length should be based on differences revealed within alternative measures of fatigue.

5.1.5 Shorter cycle times would result in smaller increases in static strength over time

Static strength in the overhead position was not affected by changes in cycle time, therefore the hypothesis was unsupported. All conditions elicited a decrease in static strength capability over time. The decrement of force production over time has been linked to the imbalance of Na^+ and K^+ across the sarcolemma which decreases the propagation of action potentials along t-tubules (Sejersted, 1992). Studies have identified increases in extracellular potassium as a result of intermittent fatiguing protocols (Sjogaard et al., 1988; Mathiassen, 1993). This imbalance reduces the rate of release of calcium from the sarcoplasmic reticulum, resulting in less actin-myosin binding within the sarcomeres of the muscle fibre, ultimately leading to reduction in muscle force generating capacity (Vollestad, 1997).

Although short cycle times influenced the trend of static strength capability over time, this condition did not produce significantly different values when compared to other conditions. Similarly, Iridiastadi and Nussbaum (2006b) found that altering cycle times did not have a significant influence on the strength of static arm abductions. The only factor affecting the rate of static strength decrease was the level of contraction of intermittent abductions. In the current study, it is possible that the force level during the overhead press (30%MVF) was too low to detect the effect of cycle time on the rate of static strength decrease. Since the overhead task was equally composed of the overhead press and release phases, the mean load of this task was lower than 30%MVF. An equation using duty cycle to predict the maximal acceptable effort over a work day was developed for repetitive tasks requiring use of the upper extremity (Potvin, 2012). Using this equation, performing overhead work at a 40% duty cycle resulted in a maximal acceptable effort of 20%MVF. The acceptable value is very close to the selected mean workload (<30%MVF) used in the current study. According to the relationship identified by Potvin (2012), the force level selected for the overhead press was likely too low to reveal the fatigue related effect of cycle time on strength capability. Results of the present and previous studies suggest that the physiological mechanisms of localized muscle fatigue are more sensitive to changes in workload compared to organization methods such as cycle time.

5.2 Limitations

As this was an experimental study conducted in a laboratory setting, the overhead work task and task rotation parameters were highly controlled. The overhead pressing task was normalized to the participant and set at 30% of participants' maximal static strength. Also, the task rotation duty cycle between the intermittent overhead and neutral assembly task was 40% across all conditions. Such strict controls are imperative in isolating differences in fatigue measures due to changes in cycle time. This amount of control is usually not found in industrial settings which limits the field application of findings.

Several methodological factors in the current study may limit the extension of findings. Allowing continuation of the protocol past three hours may have resulted in greater differences in endurance times between cycle time conditions. Specifically in the 15s condition, five out of the nine participants ended the protocol due to the three hour stopping criterion. These cases skew the average completion times reported (especially for the 15s condition) by underestimating true endurance time.

Since testing sessions occurred on different days, placement of surface electrodes may have been slightly inconsistent. Photographs were taken of placements after the first testing session and were used along with specific instructions (Criswell, 2011) to maintain consistent placements for following testing sessions. If placements were slightly inaccurate across testing sessions, it would affect which motor units were being recorded, and therefore affect the precision of measuring muscle activation across days. However, a study conducted by Daanen and colleagues (1990) revealed that the day to day variation in EMG spectral measures was small in comparison to changes influenced by a fatiguing protocol.

Measuring muscle activity via surface electromyography may have resulted in cross-talk between other active motor units from surrounding muscles. Within the shoulder girdle, many muscles are concentrated within a small space. Due to differences in origins and/or insertions, these muscles have varying lines of action and some are located deep to others. The pickup zone of surface electrodes may extend to active motor units of deep muscles and contribute to the activity recorded for the muscle of interest. Slight skin movement over muscles may also result in detection of different active motor units from the muscle of interest or possibly neighboring muscles.

Variability in overhead static strength ranged between 6% and 15% of average static strength within participants across days. Differences in strength values at baseline may induce variability in muscle activation used for normalization purposes (Nordander et al., 2004). In the current study, RMS amplitudes of tasks were normalized to maximal activation from overhead static strength exertions to decrease variability between participants (Mathiassen et al., 1995). Therefore, day to day variability in initial static strength will affect the magnitude of EMG amplitude and contribute to error in differences between cycle times.

5.3 Future work

In the current study, the effect size of cycle time condition over time on several dependant measures was moderate to large. In some cases, this finding was not supported with a statistically significant result. It is plausible that analysis of a sample size of nine participants had inadequate statistical power to detect certain differences. Similar issues were encountered in a study (n=8) comparing the physiological effects of fatigue during repetitive work simulations (Mathiassen and Winkel, 1996). To address the issue of statistical power, collection of more participants using the same protocol in the current study is recommended.

Based on previous studies investigating the fatigue effects of intermittent overhead work, the effect of duty cycle has significantly influenced various fatigue measures (Mathiassen, 1993; Nussbaum, 2001; Iridiastadi and Nussbaum, 2006b). Investigation of the effect of task rotation duty cycle (overhead work: neutral work) on fatigue measures over time may give insight into the design of intermittent overhead work. By maintaining a constant cycle time, a range of duty cycles can be tested.

Various studies investigating the fatigue effects of overhead work commonly examine the middle deltoid and upper trapezius through surface electromyography. Findings from the current study suggest that investigation of the posterior deltoid is also informative in identifying fatigue related effects. It is suggested that in future research, the posterior deltoid be included in the analysis of fatigue progression for overhead work tasks.

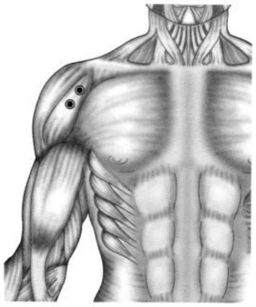
6.0 Conclusion

The present study investigated the effect of cycle time on fatigue progression during an overhead work task. Using an industrially relevant overhead work posture within a task rotation scheme increases the relevance of findings for implementation in job design. Performing intermittent overhead work for long cycles (120s) resulted in an increased level of muscle activity in the middle and posterior deltoid and reduced endurance time. By decreasing fatigue accumulation, the risk of developing shoulder musculoskeletal disorders will likely be reduced. Based on the current findings, it is recommended that intermittent overhead work be performed in shorter cycles (15s-30s) to reduce the risk of shoulder injury.

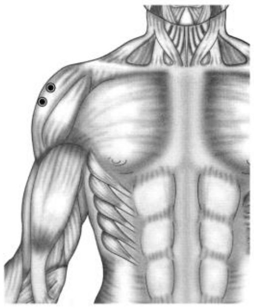
Recommendations should be taken with caution. Only two measures indicated that cycle time played a significant role in fatigue progression, making its effectiveness as a work organizational method for overhead work tasks unclear. However, effect sizes of cycle time condition over time were medium to large for certain variables implying that with more statistical power, differences due to alteration in cycle time may be revealed. Identifying additional cycle time effects on fatigue measures would provide ergonomists with more confidence in recommending this organizational strategy to mitigate the risk of musculoskeletal injury.

Appendix A

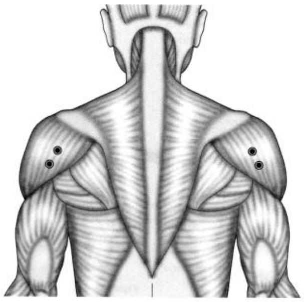
Surface electrode placements (adapted from Criswell, 2011).



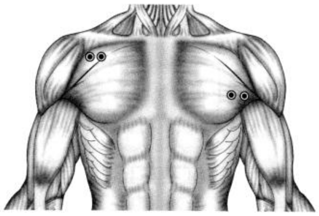
Anterior Deltoid



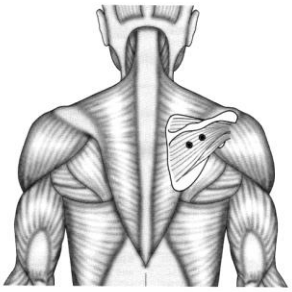
Middle Deltoid



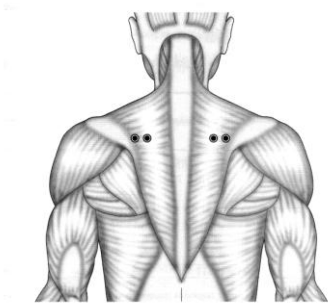
Posterior Deltoid



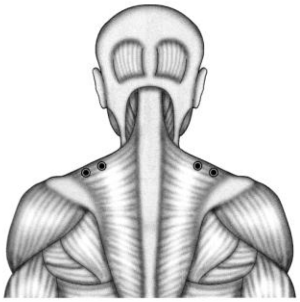
Pectoralis Major (sternal and clavicular insertions)



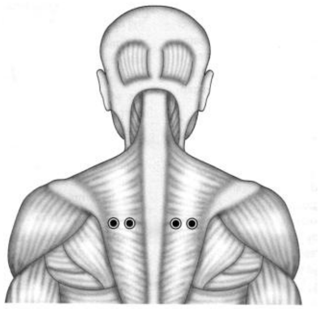
Infraspinatus



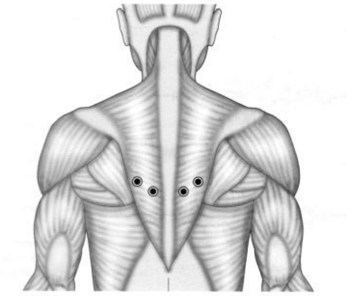
Supraspinatus



Upper Trapezius



Middle Trapezius



Lower Trapezius

Appendix B

Muscle Activation Profiles

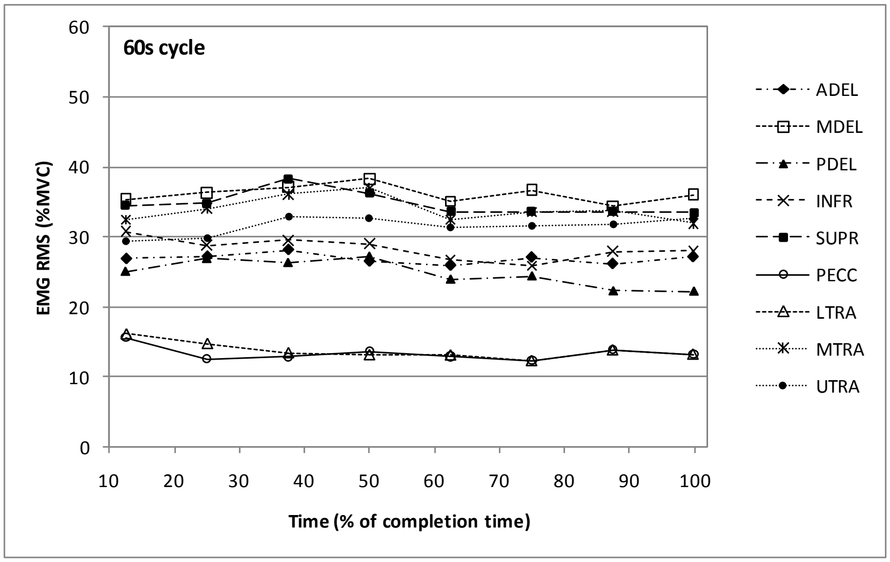


Figure 40: Activation profile of all muscles during the overhead task's press phase of the 60s cycle condition

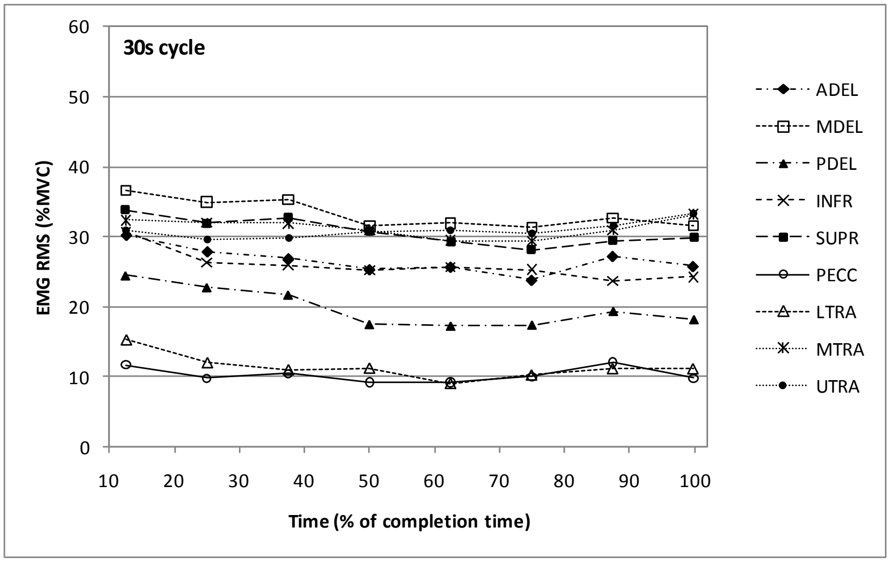


Figure 41: Activation profile of all muscles during the overhead task's press phase of the 30s cycle condition

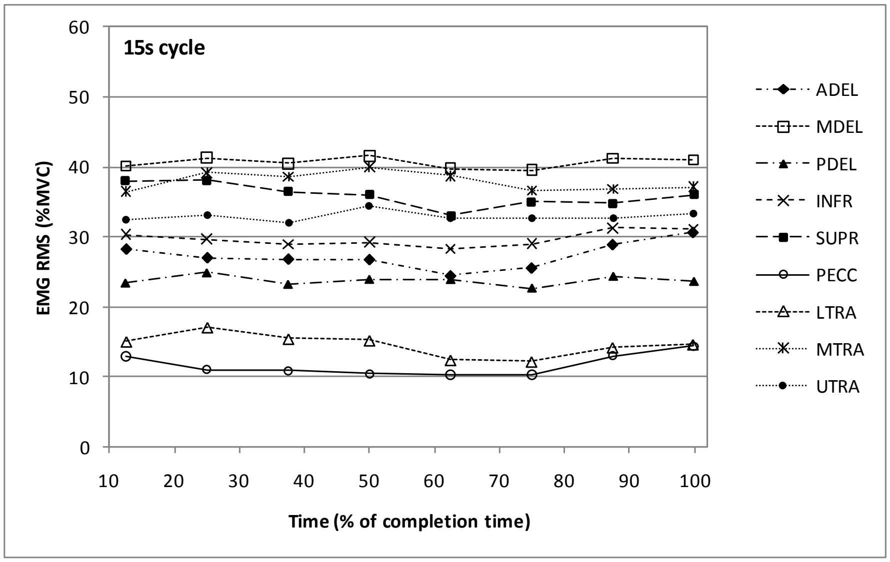


Figure 42: Activation profile of all muscles during the overhead task’s press phase of the 15s cycle condition

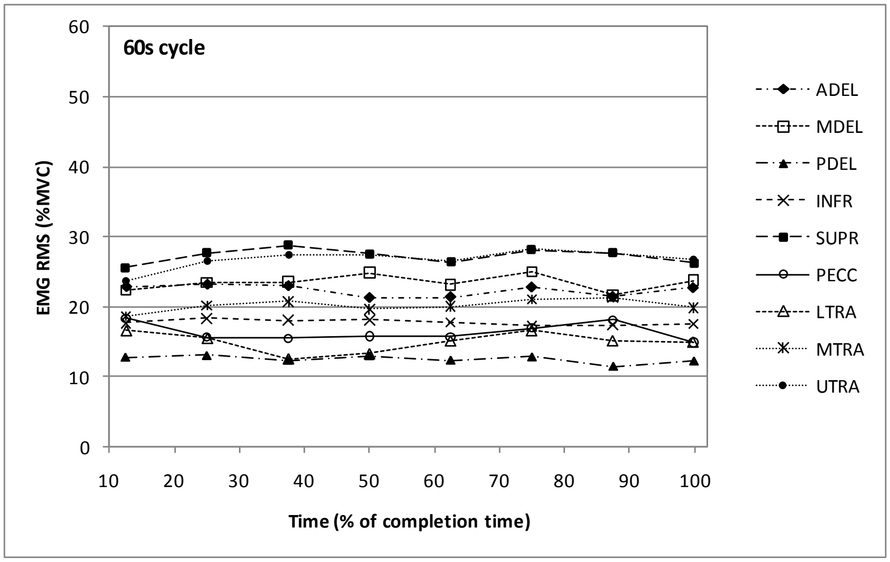


Figure 43: Activation profile of all muscles during the overhead task’s release phase of the 60s cycle condition

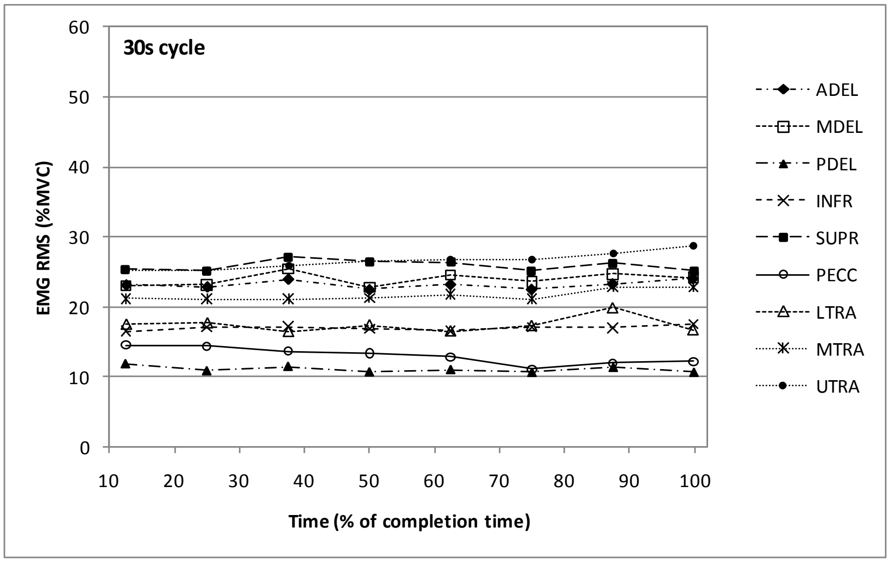


Figure 44: Activation profile of all muscles during the overhead task's release phase of the 30s cycle condition

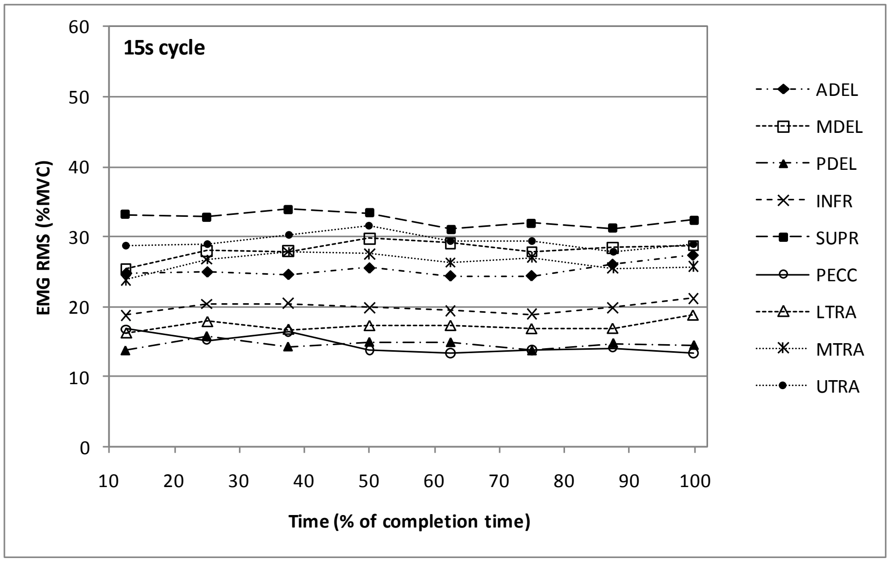


Figure 45: Activation profile of all muscles during the overhead task's release phase of the 15s cycle condition

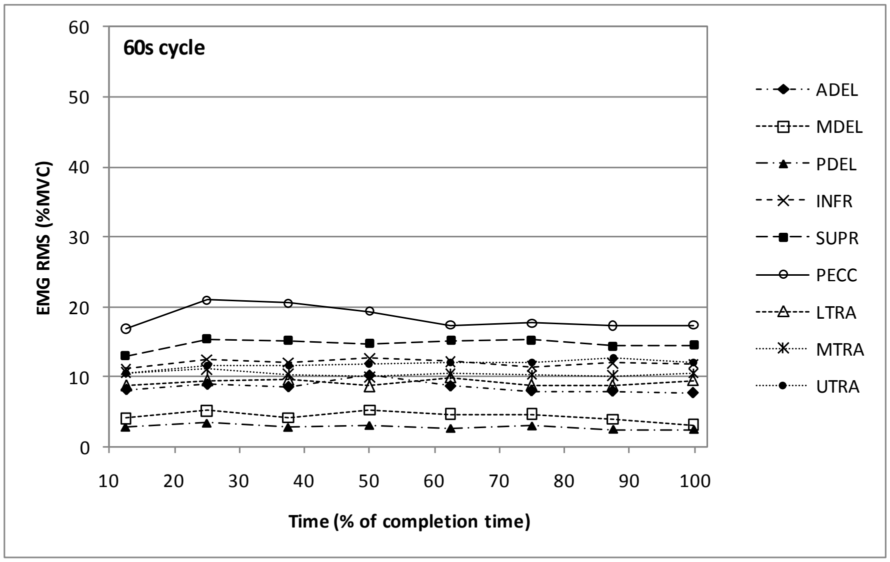


Figure 46: Activation profile of all muscles during the neutral task for the 60s cycle condition

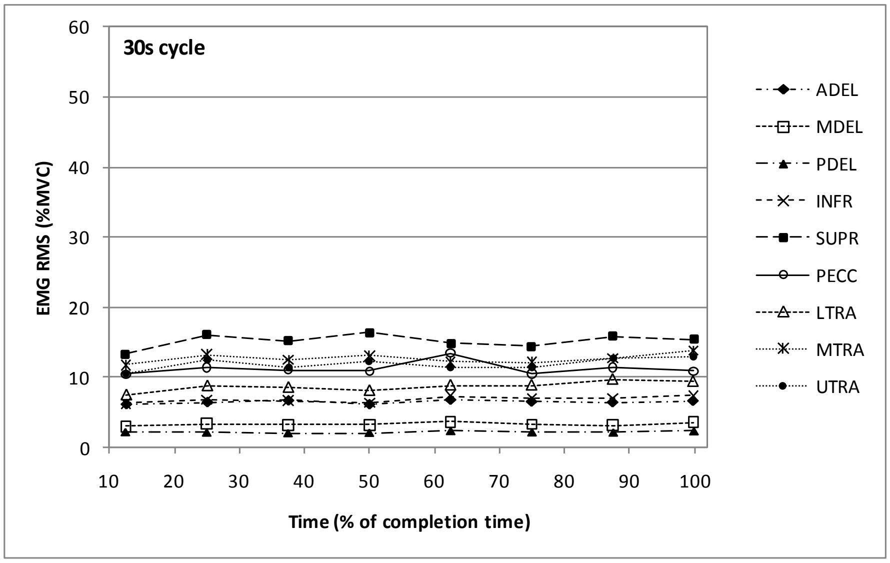


Figure 47: Activation profile of all muscles during the neutral task for the 30s cycle condition

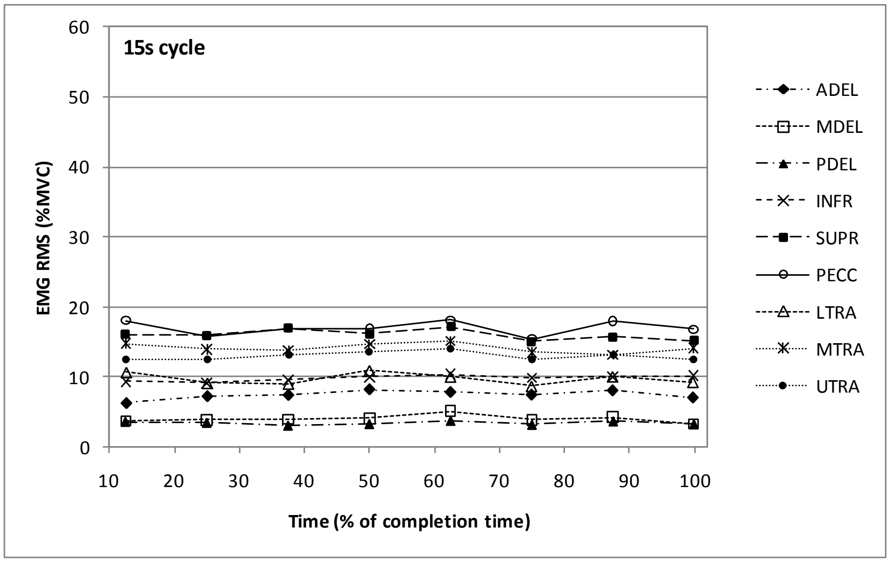


Figure 48: Activation profile of all muscles during the neutral task for the 15s cycle condition

Appendix C

Statistical Analysis

Table 11: Statistical analysis of endurance time

Factor	**Mauchly's Test**	**H-F ε**	**F-ratio**	**P value**	η_p^2
Condition	$\chi^2(5) = 4.52$ $p = 0.4770$	-	3.96	0.0200	0.33

Table 12: Statistical analysis of the rate of rating of perceived exertion over time

Factor	**Mauchly's Test**	**H-F ε**	**F-ratio**	**P value**	η_p^2
Condition	$\chi^2(5) = 11.10$ $p = 0.0494$	0.6078	3.64	0.0556	0.31

Table 13: Statistical analysis of the rate of static strength over time

Factor	**Mauchly's Test**	**H-F ε**	**F-ratio**	**P value**	η_p^2
Condition	$\chi^2(5) = 2.93$ $p = 0.7106$	-	2.91	0.0554	0.27

Table 14: Statistical analysis of anterior deltoid median power frequency

Factor		**Mauchly's Test**	**H-F ε**	**F-ratio**	**P value**	**η_p^2**
Condition		-	-	1.06	0.3824	0.12
	Pre-Post	$\chi^2(5) = 7.46$ $p = 0.1885$	-	0.80	0.5035	
Time		-	-	3.92	0.0008	0.33
	120s	-	-	2.32	0.0306	0.23
	60s	$\chi^2(35) = 37.68$ $p = 0.3478$	-	4.58	0.0002	0.36
	30s	$\chi^2(35) = 48.33$ $p = 0.0663$	-	0.56	0.8097	0.06
	15s	$\chi^2(35) = 76.51$ $p < 0.0001$	0.5269	1.40	0.2538	0.15
Condition * Time		-	-	0.76	0.7860	0.09

Table 15: Statistical analysis of middle deltoid median power frequency

Factor		**Mauchly's Test**	**H-F ε**	**F-ratio**	**P value**	**η_p^2**
Condition		-	-	0.83	0.4910	0.09
	Pre-Post	$\chi^2(5) = 1.58$ $p = 0.9041$	-	0.86	0.4752	
Time		-	-	1.19	0.3169	0.13
	120s	-	-	0.64	0.7402	0.08
	60s	$\chi^2(35) = 95.87$ $p < 0.0001$	0.3898	0.93	0.4456	0.10
	30s	$\chi^2(35) = 77.89$ $p < 0.0001$	0.4000	0.73	0.5496	0.08
	15s	$\chi^2(35) = 61.37$ $p = 0.0038$	0.4913	1.49	0.2290	0.16
Condition * Time		-	-	0.77	0.7756	0.09

Table 16: Statistical analysis of posterior deltoid median power frequency

Factor		**Mauchly's Test**	**H-F ε**	**F-ratio**	**P value**	η_p^2
Condition		-	-	1.34	0.2860	0.14
	Pre-Post	$\chi^2(5) = 5.53$ $p = 0.3547$	-	0.87	0.4705	
Time		-	-	1.14	0.3482	0.12
	120s	-	-	1.04	0.4159	0.12
	60s	$\chi^2(35) = 27.82$ $p = 0.8005$	-	4.08	0.0006	0.34
	30s	$\chi^2(35) = 49.70$ $p = 0.0510$	-	1.02	0.4299	0.11
	15s	$\chi^2(35) = 59.57$ $p = 0.0059$	0.2442	0.53	0.5971	0.06
Condition * Time		-	-	1.21	0.2357	0.13

Table 17: Statistical analysis of infraspinatus median power frequency

Factor		**Mauchly's Test**	**H-F ε**	**F-ratio**	**P value**	η_p^2
Condition		-	-	0.47	0.7032	0.06
	Pre-Post	$\chi^2(5) = 5.39$ $p = 0.3705$	-	0.18	0.9075	
Time		-	-	5.34	<0.0001	0.40
	120s	-	-	3.97	0.0008	0.34
	60s	$\chi^2(35) = 49.12$ $p = 0.0571$	-	2.03	0.0568	0.20
	30s	$\chi^2(35) = 55.53$ $p = 0.0151$	0.6251	1.47	0.2196	0.16
	15s	$\chi^2(35) = 56.70$ $p = 0.0116$	0.5951	2.10	0.0890	0.21
Condition * Time		-	-	0.80	0.7368	0.09

Table 18: Statistical analysis of supraspinatus median power frequency

Factor		**Mauchly's Test**	**H-F ε**	**F-ratio**	**P value**	**η_p^2**
Condition		-	-	0.23	0.8780	0.03
	Pre-Post	$\chi^2(5) = 7.33$ p = 0.1974	-	0.09	0.9631	
Time		-	-	9.38	<0.0001	0.54
	120s	-	-	2.22	0.0381	0.23
	60s	$\chi^2(35) = 36.79$ p = 0.3862	-	3.40	0.0026	0.30
	30s	$\chi^2(35) = 40.10$ p = 0.2543	-	5.91	<0.0001	0.42
	15s	$\chi^2(35) = 60.77$ p = 0.0044	0.7980	4.84	0.0004	0.38
Condition * Time		-	-	0.59	0.9379	0.07

Table 19: Statistical analysis of middle trapezius median power frequency

Factor		**Mauchly's Test**	**H-F ε**	**F-ratio**	**P value**	**η_p^2**
Condition		-	-	0.68	0.5724	0.08
	Pre-Post	$\chi^2(5) = 12.14$ p = 0.0329	0.7915	0.65	0.5573	
Time		-	-	10.7	<0.0001	0.57
	120s	-	-	3.23	0.0039	0.30
	60s	$\chi^2(35) = 50.16$ p = 0.0466	0.6726	2.38	0.0507	0.23
	30s	$\chi^2(35) = 25.41$ p = 0.8828	-	4.49	0.0002	0.36
	15s	$\chi^2(35) = 55.52$ p = 0.0151	0.5392	2.04	0.1057	0.20
Condition * Time		-	-	0.65	0.8972	0.08

Table 20: Statistical analysis of upper trapezius median power frequency

Factor		**Mauchly's Test**	**H-F ε**	**F-ratio**	**P value**	η_p^2
Condition		-	-	0.06	0.9822	0.01
	Pre-Post	$\chi^2(5) = 9.88$ $p = 0.0788$	-	0.09	0.9670	
Time		-	-	7.66	<0.0001	0.49
	120s	-	-	4.32	0.0004	0.36
	60s	$\chi^2(35) = 75.83$ $p < 0.0001$	0.7310	2.58	0.0315	0.24
	30s	$\chi^2(35) = 46.39$ $p = 0.0943$	-	2.38	0.0259	0.23
	15s	$\chi^2(35) = 47.64$ $p = 0.0753$	-	5.02	<0.0001	0.39
Condition * Time		-	-	0.74	0.8004	0.09

Table 21: Statistical analysis of anterior deltoid root mean square amplitude

Factor		**Mauchly's Test**	**H-F ε**	**F-ratio**	**P value**	η_p^2
Condition		-	-	1.82	0.1698	0.19
	Pre-Post	$\chi^2(5) = 10.49$ $p = 0.0625$	-	1.61	0.2123	
Time		-	-	1.86	0.0828	0.19
	120s	-	-	1.84	0.0871	0.19
	60s	$\chi^2(35) = 51.73$ $p = 0.0340$	0.7825	0.42	0.8658	0.05
	30s	$\chi^2(35) = 63.61$ $p = 0.0022$	0.5311	2.60	0.0505	0.25
	15s	$\chi^2(35) = 79.86$ $p < 0.0001$	0.3184	1.07	0.3770	0.12
Condition * Time		-	-	1.18	0.2608	0.13

Table 22: Statistical analysis of middle deltoid root mean square amplitude

Factor		**Mauchly's Test**	**H-F ε**	**F-ratio**	**P value**	**η_p^2**
Condition		-	-	10.76	0.0001	0.57
	Pre-Post	$\chi^2(5) = 7.16$ $p = 0.2088$	-	9.39	0.0003	
Time		-	-	7.11	<0.0001	0.47
	120s	-	-	11.84	<0.0001	0.61
	60s	$\chi^2(35) = 37.90$ $p = 0.3385$	-	4.86	0.0001	0.38
	30s	$\chi^2(35) = 72.77$ $p = 0.0002$	0.2941	2.54	0.0985	0.24
	15s	$\chi^2(35) = 90.72$ $p < 0.0001$	0.3864	2.21	0.1106	0.22
Condition * Time		-	-	3.10	<0.0001	0.28

Table 23: Statistical analysis of posterior deltoid root mean square amplitude

Factor		**Mauchly's Test**	**H-F ε**	**F-ratio**	**P value**	**η_p^2**
Condition		-	-	5.44	0.0053	0.40
	Pre-Post	$\chi^2(5) = 4.35$ $p = 0.5002$	-	10.17	0.0002	
Time		-	-	8.8	<0.0001	0.52
	120s	-	-	17.25	<0.0001	0.48
	60s	$\chi^2(35) = 99.63$ $p < 0.0001$	0.1854	2.92	0.1029	0.27
	30s	$\chi^2(35) = 80.48$ $p < 0.0001$	0.2222	2.08	0.1646	0.21
	15s	$\chi^2(35) = 109.62$ $p < 0.0001$	0.4501	2.44	0.0753	0.23
Condition * Time		-	-	2.52	0.0003	0.24

Table 24: Statistical analysis of infraspinatus root mean square amplitude

Factor		**Mauchly's Test**	**H-F ε**	**F-ratio**	**P value**	**η_p^2**
Condition		-	-	0.74	0.5374	0.08
	Pre-Post	$\chi^2(5) = 6.72$ $p = 0.2423$	-	0.87	0.4686	
Time		-	-	2.54	0.0182	0.24
	120s	-	-	1.51	0.1731	0.17
	60s	$\chi^2(35) = 68.59$ $p = 0.0006$	0.6800	1.49	0.2099	0.16
	30s	$\chi^2(35) = 70.38$ $p = 0.0004$	0.3098	0.89	0.4480	0.10
	15s	$\chi^2(35) = 78.44$ $p < 0.0001$	0.5308	0.92	0.4688	0.10
Condition * Time		-	-	0.64	0.9039	0.07

Table 25: Statistical analysis of supraspinatus root mean square amplitude

Factor		**Mauchly's Test**	**H-F ε**	**F-ratio**	**P value**	**η_p^2**
Condition		-	-	1.48	0.2441	0.16
	Pre-Post	$\chi^2(5) = 17.99$ $p = 0.0030$	0.5029	1.60	0.2394	
Time		-	-	2.62	0.0150	0.25
	120s	-	-	2.47	0.0215	0.25
	60s	$\chi^2(35) = 94.21$ $p < 0.0001$	0.4880	1.76	0.1629	0.18
	30s	$\chi^2(35) = 86.79$ $p < 0.0001$	0.4531	1.25	0.3134	0.13
	15s	$\chi^2(35) = 126.55$ $p < 0.0001$	0.1829	1.86	0.2006	0.19
Condition * Time		-	-	1.46	0.0850	0.16

Table 26: Statistical analysis of middle trapezius root mean square amplitude

Factor		**Mauchly's Test**	**H-F ε**	**F-ratio**	**P value**	**η_p^2**
Condition		-	-	2.3	0.103	0.22
	Pre-Post	$\chi^2(5) = 7.73$ $p = 0.1719$	-	1.3	0.2982	
Time		-	-	10.23	<0.0001	0.56
	120s	-	-	8.11	<0.0001	0.52
	60s	$\chi^2(35) = 43.72$ $p = 0.1482$	-	3.64	0.0015	0.31
	30s	$\chi^2(35) = 91.44$ $p < 0.0001$	0.3704	1.3	0.2982	0.14
	15s	$\chi^2(35) = 71.01$ $p = 0.0003$	0.6478	4.9	0.0012	0.38
Condition * Time		-	-	0.9	0.5968	0.10

Table 27: Statistical analysis of upper trapezius root mean square amplitude

Factor		**Mauchly's Test**	**H-F ε**	**F-ratio**	**P value**	**η_p^2**
Condition		-	-	1.58	0.2205	0.16
	Pre-Post	$\chi^2(5) = 4.95$ $p = 0.4221$	-	0.57	0.6419	
Time		-	-	4.69	0.0001	0.37
	120s	-	-	3.92	0.0009	0.34
	60s	$\chi^2(35) = 92.37$ $p < 0.0001$	0.4832	2.63	0.0547	0.25
	30s	$\chi^2(35) = 54.37$ $p = 0.0194$	0.4788	0.55	0.6910	0.06
	15s	$\chi^2(35) = 55.73$ $p = 0.0144$	0.4902	1.53	0.2178	0.16
Condition * Time		-	-	0.75	0.7983	0.09

Appendix D

Regression Analysis

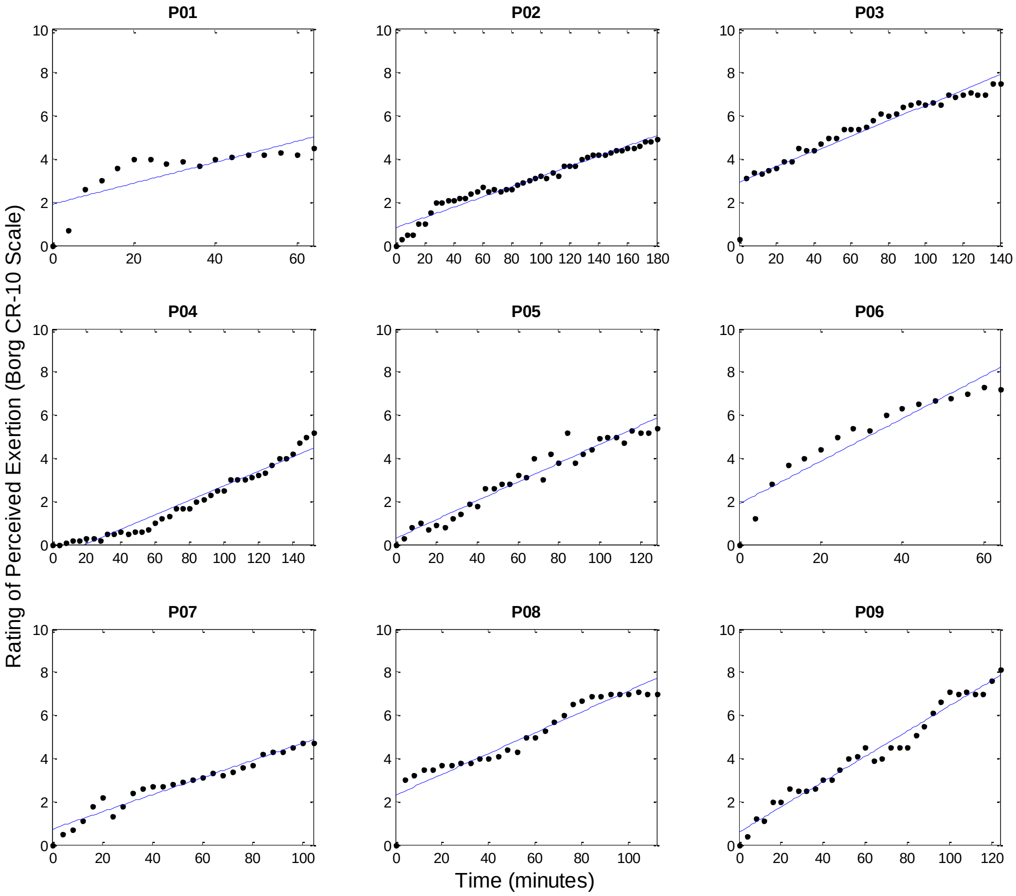


Figure 49: Linear regression analysis of rate of perceived exertion over time for the 120s condition

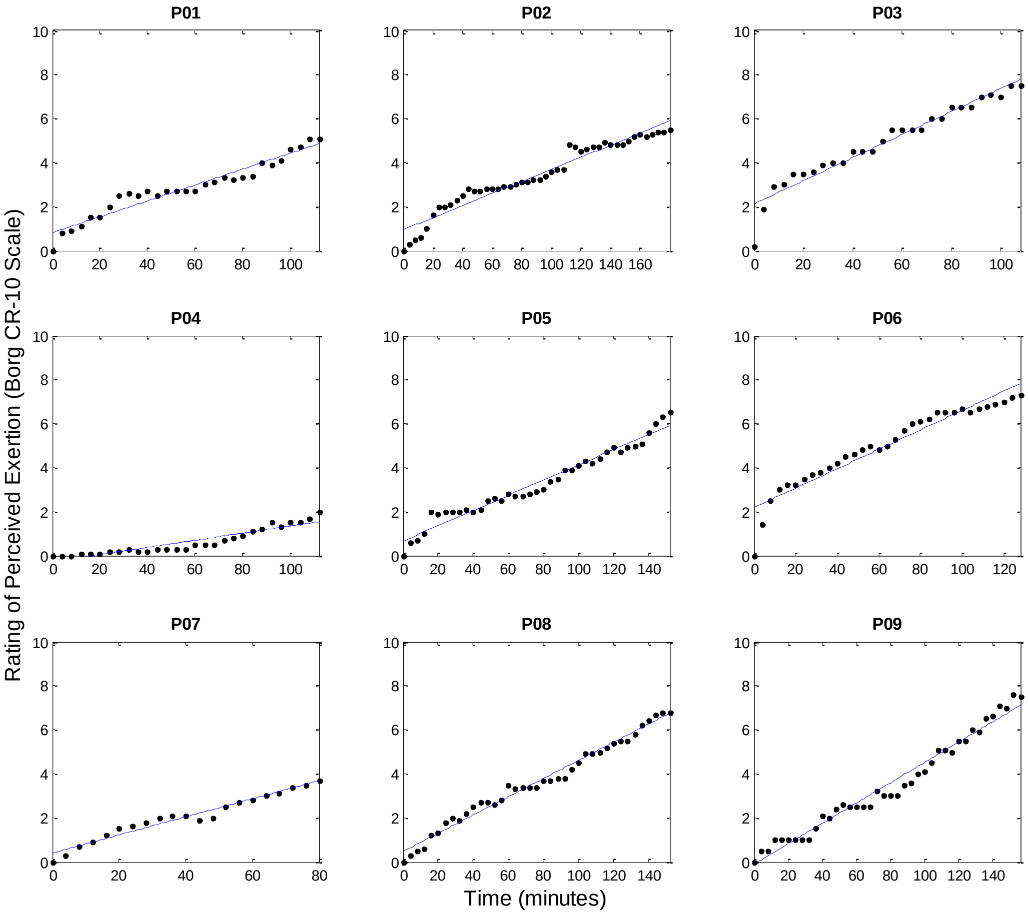


Figure 50: Linear regression analysis of rate of perceived exertion over time for the 60s condition

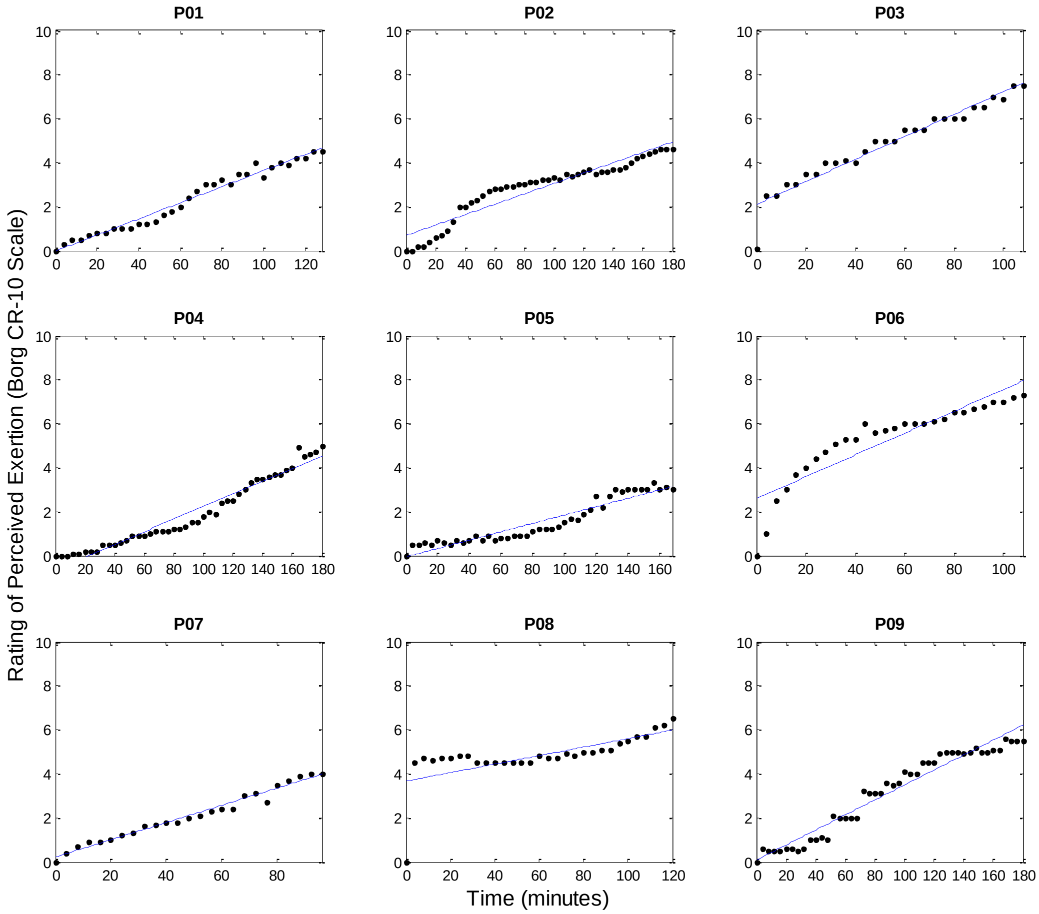


Figure 51: Linear regression analysis of rate of perceived exertion over time for the 30s condition

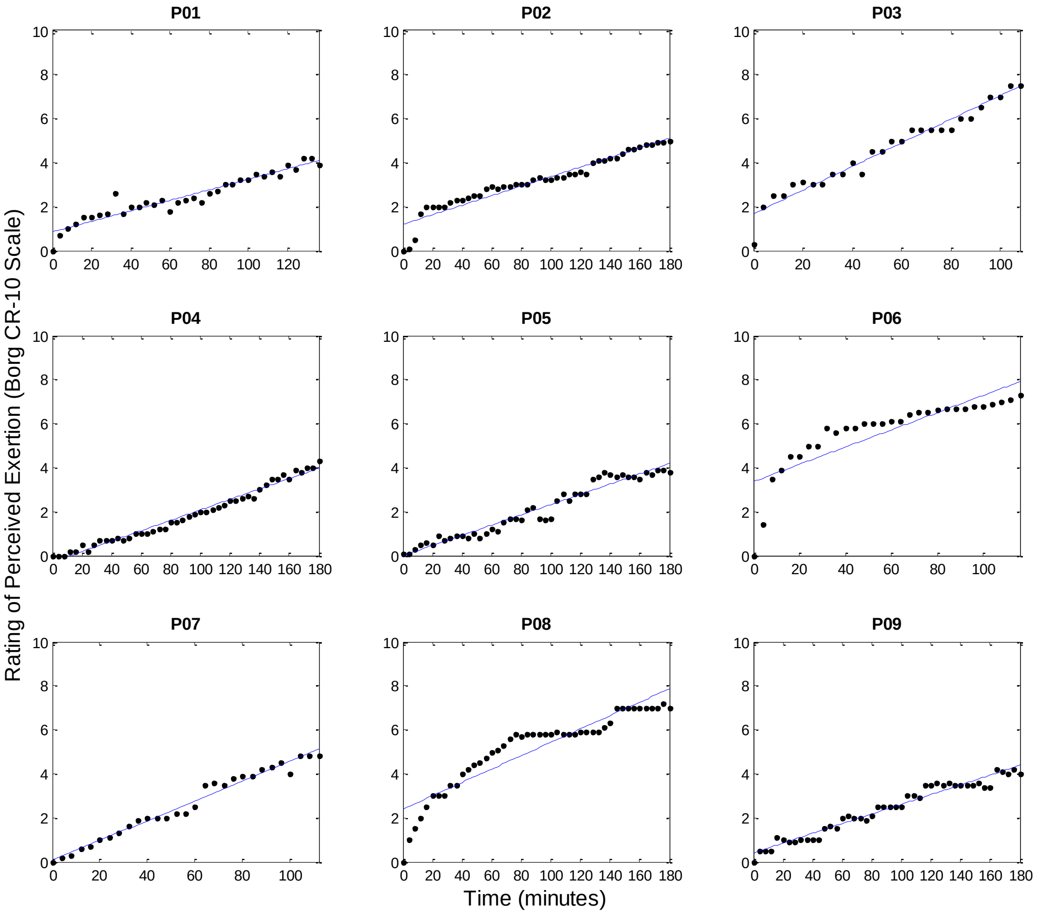


Figure 52: Linear regression analysis of rate of perceived exertion over time for the 15s condition

Table 28: Results of the linear regression analysis for rating of perceived exertion over time

Condition	Participant	Slope	Y-intercept	r^2
120s	P01	0.0486	1.9039	0.6011
	P02	0.0237	0.8119	0.9524
	P03	0.0355	2.9260	0.8913
	P04	0.0337	-0.6423	0.9549
	P05	0.0435	0.2800	0.9492
	P06	0.0988	1.8725	0.8764
	P07	0.0399	0.7201	0.9455
	P08	0.0483	2.2966	0.8927
	P09	0.0586	0.5744	0.9715
60s	P01	0.0362	0.8083	0.9324
	P02	0.0275	0.9364	0.9421
	P03	0.0525	2.1133	0.9372
	P04	0.0163	-0.2807	0.8819
	P05	0.0346	0.6624	0.9621
	P06	0.0442	2.1736	0.9156
	P07	0.0410	0.3965	0.9620
	P08	0.0414	0.4647	0.9827
	P09	0.0464	-0.1210	0.9739
30s	P01	0.0366	-0.0292	0.9738
	P02	0.0236	0.6827	0.8948
	P03	0.0511	2.1005	0.9327
	P04	0.0285	-0.6286	0.9523
	P05	0.0190	-0.0592	0.9000
	P06	0.0496	2.5865	0.8030
	P07	0.0392	0.2129	0.9769
	P08	0.0194	3.6601	0.4498
	P09	0.0341	0.0806	0.9530
15s	P01	0.0239	0.8471	0.9178
	P02	0.0217	1.1940	0.9182
	P03	0.0538	1.6650	0.9575
	P04	0.0237	-0.2938	0.9790
	P05	0.0233	-0.0081	0.9516
	P06	0.0392	3.3598	0.6988
	P07	0.0451	0.0655	0.9760
	P08	0.0304	2.3906	0.8493
	P09	0.0221	0.4049	0.9588

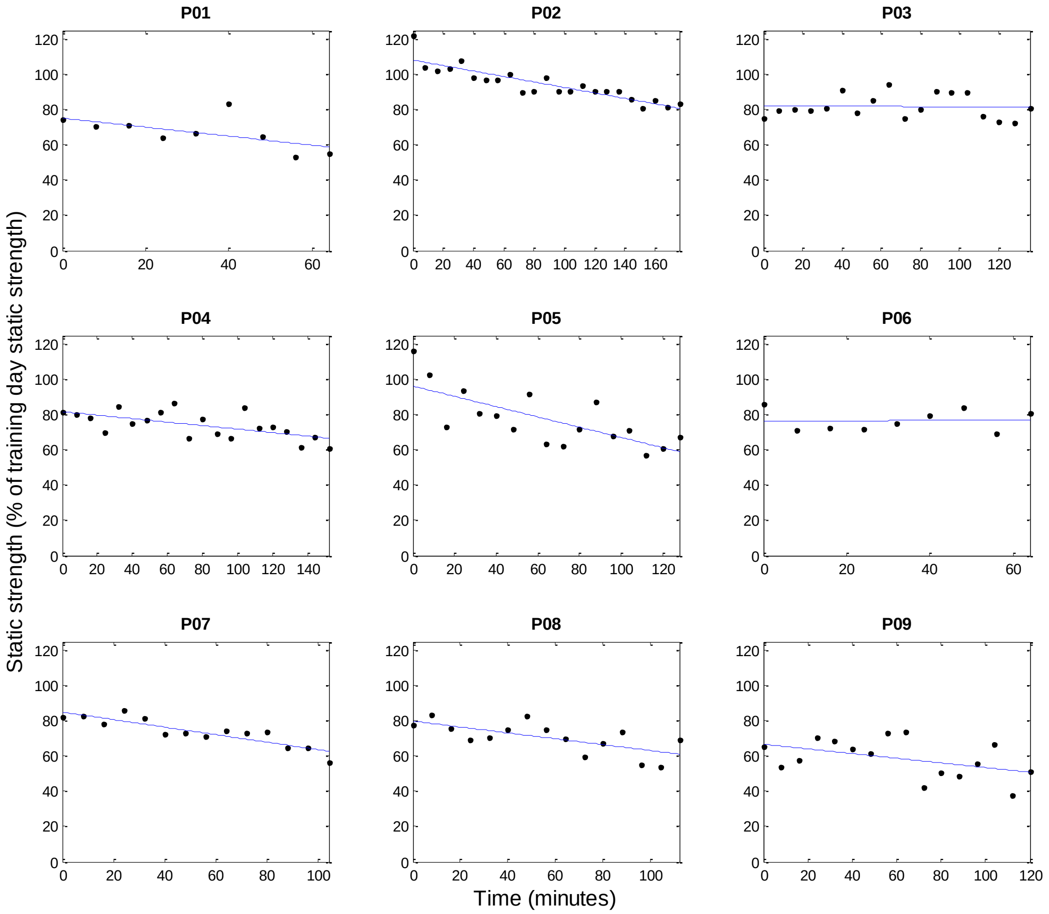


Figure 53: Linear regression analysis of static strength over time for the 120s condition

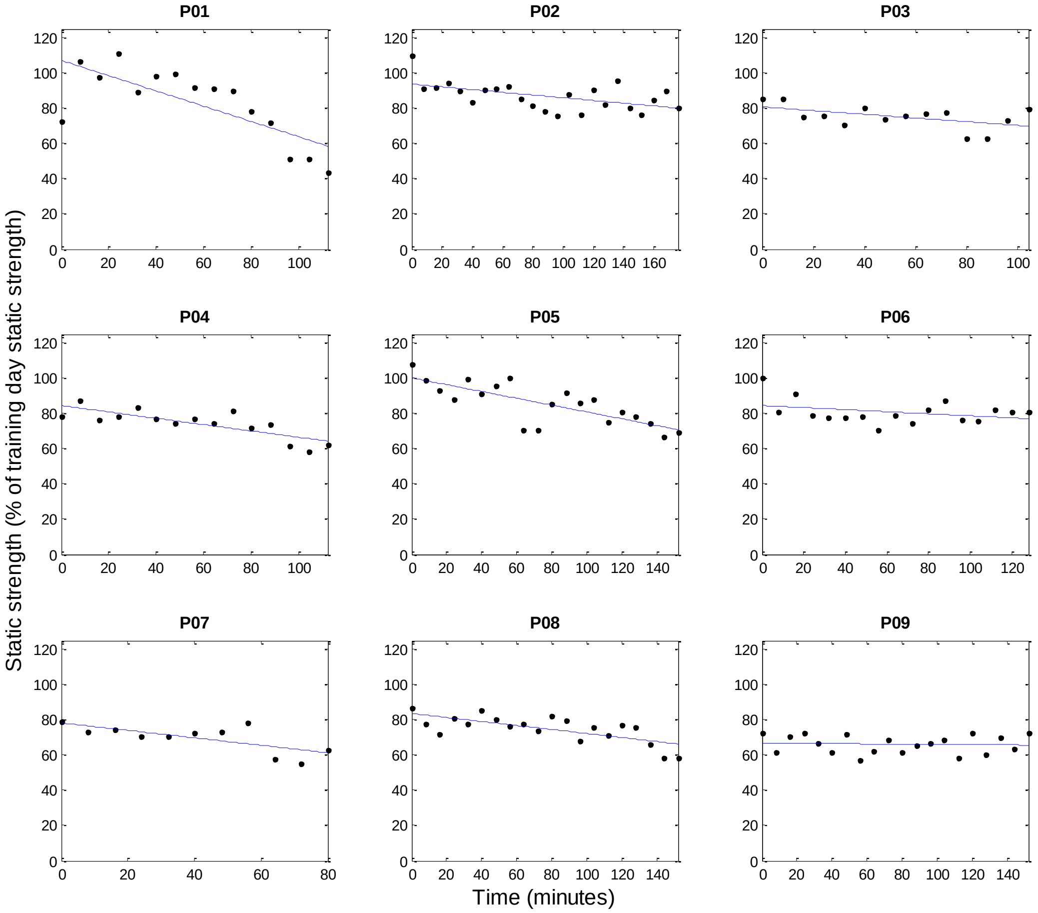


Figure 54: Linear regression analysis of static strength over time for the 60s condition

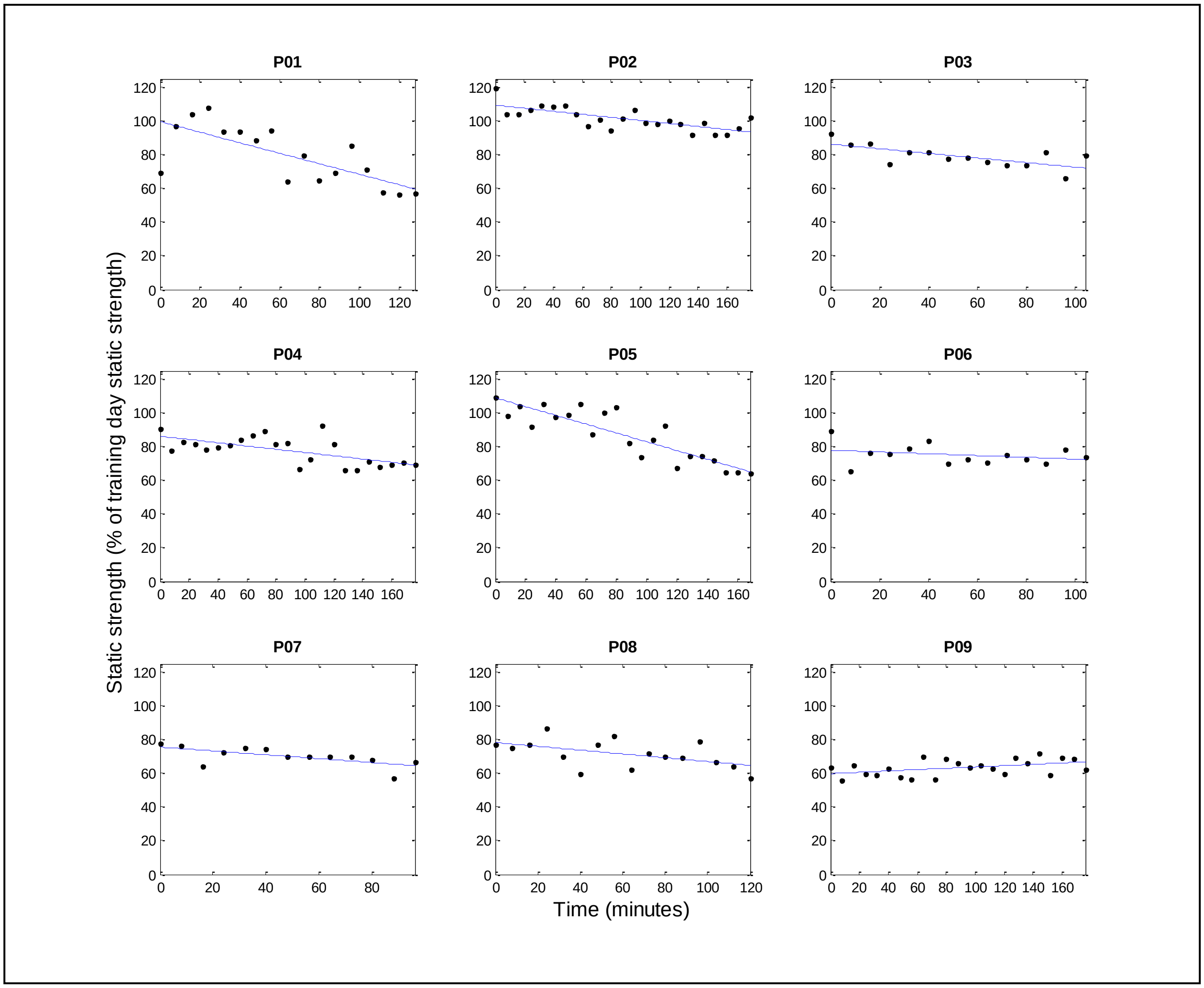


Figure 55: Linear regression analysis of static strength over time for the 30s condition

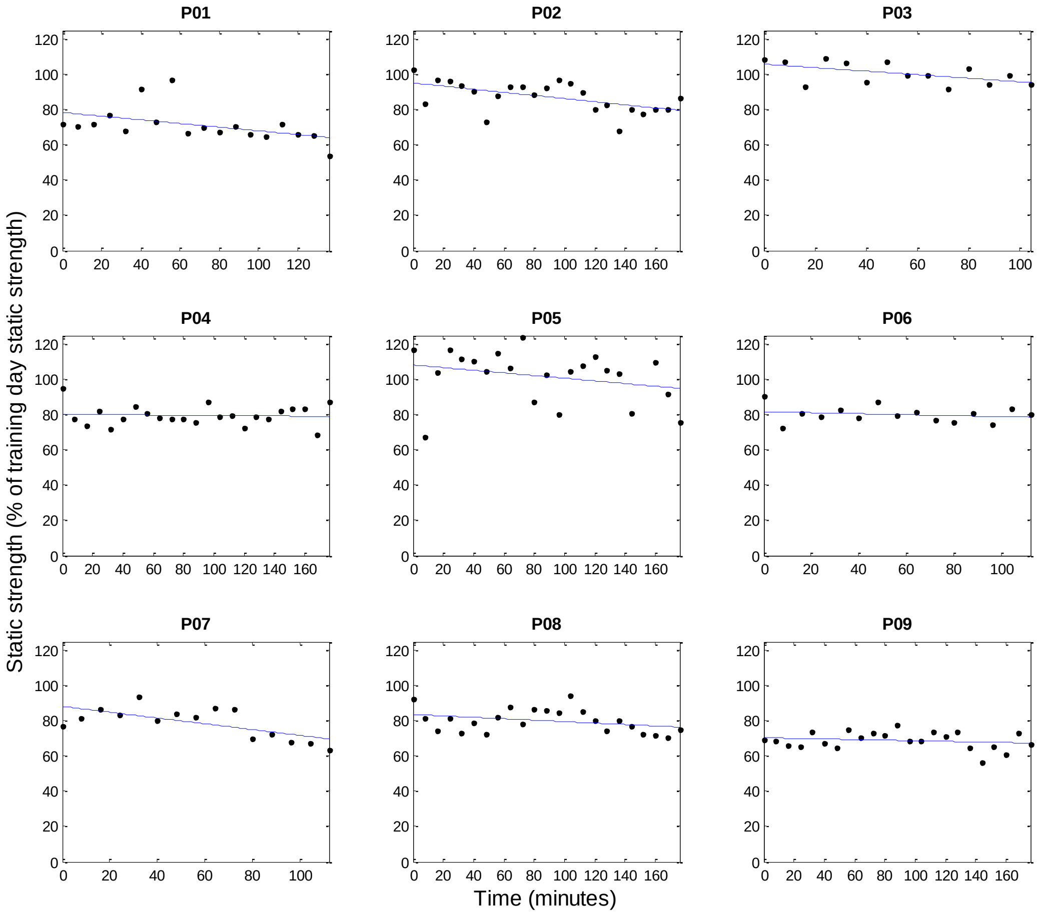


Figure 56: Linear regression analysis of static strength over time for the 15s condition

Table 29: Results of the linear regression analysis for static strength over time

Condition	Participant	Slope	Y-intercept	r^2
120s	P01	-0.2558	75.2089	0.3660
	P02	-0.1552	108.2010	0.7860
	P03	-0.0067	82.2999	0.0017
	P04	-0.0994	81.7869	0.3856
	P05	-0.2919	96.3008	0.5303
	P06	0.0086	76.4175	0.0009
	P07	-0.2138	85.0087	0.7743
	P08	-0.1673	79.8890	0.4579
	P09	-0.1328	66.7336	0.2151
60s	P01	-0.4344	107.2025	0.5551
	P02	-0.0772	93.7189	0.2864
	P03	-0.1051	80.7893	0.2682
	P04	-0.1803	84.4891	0.6236
	P05	-0.1940	100.2620	0.5957
	P06	-0.0581	84.5068	0.1199
	P07	-0.2112	78.2337	0.4976
	P08	-0.1142	83.6329	0.4982
	P09	-0.0071	66.7641	0.0043
30s	P01	-0.3121	99.6429	0.5398
	P02	-0.0910	109.4963	0.5363
	P03	-0.1375	86.3219	0.4786
	P04	-0.0966	86.1923	0.4053
	P05	-0.2616	109.0092	0.7759
	P06	-0.0525	77.8775	0.0842
	P07	-0.1148	75.6002	0.4164
	P08	-0.1124	78.2724	0.2681
	P09	0.0396	59.8281	0.2001
15s	P01	-0.1043	78.4266	0.2130
	P02	-0.0884	95.1747	0.3122
	P03	-0.1011	105.9489	0.2911
	P04	-0.0068	80.2697	0.0043
	P05	-0.0758	108.3315	0.0743
	P06	-0.0281	81.7324	0.0458
	P07	-0.1647	88.2325	0.4465
	P08	-0.0410	83.6902	0.1113
	P09	-0.0171	70.4522	0.0360

Table 30: Results of the linear regression analysis of anterior deltoid median power frequency over time

Condition	Participant	Slope	Y-intercept	r^2
120s	P01	-0.1497	103.8873	0.5693
	P02	-0.0453	93.1323	0.2719
	P03	-0.1045	87.1794	0.4225
	P04	-0.0051	92.6977	0.0029
	P05	-0.0367	102.1334	0.1135
	P06	0.1328	109.4211	0.1458
	P07	-0.0506	98.7169	0.2146
	P08	-0.0449	92.7844	0.0848
	P09	-0.0445	96.0042	0.1961
60s	P01	0.0802	96.8441	0.2165
	P02	-0.0899	100.2394	0.6941
	P03	-0.1626	93.3218	0.6840
	P04	0.0054	95.5865	0.0020
	P05	-0.0439	99.3149	0.1846
	P06	-0.0338	98.0632	0.1307
	P07	-0.1243	91.2597	0.3366
	P08	-0.0488	98.9903	0.2986
	P09	-0.0328	96.5312	0.1820
30s	P01	0.0071	96.5868	0.0029
	P02	-0.0183	91.3170	0.0445
	P03	-0.1238	87.4873	0.4202
	P04	0.0307	96.9925	0.0896
	P05	-0.0443	108.3074	0.1531
	P06	0.1591	104.2426	0.4488
	P07	-0.0877	93.3680	0.4628
	P08	-0.0845	101.0092	0.2502
	P09	-0.0407	104.6180	0.3027
15s	P01	0.0194	105.1886	0.0306
	P02	-0.0364	85.1546	0.1215
	P03	-0.0346	112.3720	0.0292
	P04	-0.0281	96.5349	0.1398
	P05	-0.0715	100.9091	0.5933
	P06	-0.0168	103.4427	0.0106
	P07	-0.0762	100.0212	0.3748
	P08	-0.0280	99.6620	0.0996
	P09	-0.0329	107.2096	0.2003

Table 31: Results of the linear regression analysis of middle deltoid median power frequency over time

Condition	**Participant**	**Slope**	**Y-intercept**	**r^2**
120s	P01	0.0890	99.5255	0.2698
	P02	0.0114	99.3840	0.0307
	P03	-0.0144	104.4886	0.0160
	P04	0.0010	103.4347	0.0001
	P05	0.0270	99.0240	0.1379
	P06	0.0928	98.6839	0.2963
	P07	-0.0478	94.1854	0.0806
	P08	-0.0447	104.8622	0.0740
	P09	0.0255	101.1837	0.0880
60s	P01	-0.1142	123.7766	0.1103
	P02	0.0047	104.5885	0.0048
	P03	-0.0328	94.6573	0.0811
	P04	0.0693	111.8811	0.1376
	P05	-0.0240	98.5219	0.0618
	P06	0.0494	87.6637	0.1448
	P07	-0.0585	88.8782	0.0648
	P08	-0.0503	114.6793	0.0585
	P09	-0.0072	105.1506	0.0111
30s	P01	-0.2206	131.4195	0.3323
	P02	0.0103	98.9059	0.0307
	P03	-0.1229	96.2506	0.6488
	P04	0.0036	99.6527	0.0024
	P05	-0.0401	117.4329	0.1036
	P06	0.0869	115.7644	0.1274
	P07	-0.0017	91.6185	0.0001
	P08	0.2937	90.7373	0.7952
	P09	0.0355	113.5838	0.0898
15s	P01	0.0164	97.2920	0.0100
	P02	-0.0020	98.3140	0.0008
	P03	0.0790	103.4751	0.2949
	P04	-0.0284	110.0068	0.0365
	P05	0.0419	104.9115	0.1748
	P06	0.0003	106.0816	0.0000
	P07	-0.0450	99.6717	0.4223
	P08	0.1263	108.2458	0.4168
	P09	0.0179	101.5113	0.0538

Table 32: Results of the linear regression analysis of posterior deltoid median power frequency over time

Condition	Participant	Slope	Y-intercept	r^2
120s	P01	-0.2443	96.1113	0.4755
	P02	0.0042	105.1061	0.0040
	P03	-0.0176	106.6676	0.0399
	P04	-0.0266	87.7054	0.0801
	P05	0.0102	103.4287	0.0046
	P06	0.0014	93.3310	0.0000
	P07	-0.0334	92.0114	0.0290
	P08	-0.0334	95.8599	0.1158
	P09	0.0000	98.8762	0.0000
60s	P01	-0.0254	94.4604	0.0170
	P02	-0.0067	95.6729	0.0201
	P03	-0.0588	101.2889	0.3364
	P04	-0.0407	96.5376	0.1411
	P05	0.0144	98.7781	0.0202
	P06	-0.0439	83.4555	0.0839
	P07	-0.0505	90.9317	0.0583
	P08	0.0031	96.6381	0.0010
	P09	-0.0141	97.6562	0.0211
30s	P01	0.0747	98.2725	0.0921
	P02	0.0116	97.9634	0.0286
	P03	-0.0547	102.6369	0.1738
	P04	-0.0247	95.5093	0.0600
	P05	-0.0371	98.2140	0.2051
	P06	0.0562	102.2164	0.1547
	P07	-0.0740	95.4478	0.2448
	P08	0.2408	94.0620	0.6797
	P09	0.0303	121.7039	0.0303
15s	P01	0.0002	112.1679	0.0000
	P02	-0.0187	95.6880	0.0934
	P03	0.0893	102.8924	0.2353
	P04	-0.0008	96.9383	0.0001
	P05	-0.0717	69.6296	0.1987
	P06	-0.0486	91.7195	0.1286
	P07	-0.0129	92.5455	0.0103
	P08	0.0676	99.8312	0.3366
	P09	0.0654	112.0719	0.1918

Table 33: Results of the linear regression analysis of infraspinatus median power frequency over time

Condition	Participant	Slope	Y-intercept	r^2
120s	P01	-0.3323	91.0230	0.5095
	P02	-0.0438	96.2188	0.1362
	P03	-0.0717	92.1955	0.3632
	P04	0.0136	93.9052	0.0057
	P05	0.0511	87.0973	0.0709
	P06	0.0061	94.8321	0.0005
	P07	-0.0401	87.8809	0.0420
	P08	0.0006	97.7829	0.0000
	P09	0.0010	99.0105	0.0000
60s	P01	0.2607	64.7871	0.2279
	P02	-0.0767	92.4967	0.3107
	P03	-0.1175	89.8013	0.4334
	P04	-0.0070	83.0307	0.0009
	P05	-0.0004	97.2757	0.0000
	P06	0.0686	92.6985	0.2499
	P07	-0.2229	101.1479	0.6089
	P08	-0.0307	96.6991	0.0816
	P09	0.0133	101.5186	0.0138
30s	P01	0.1478	77.2483	0.1657
	P02	-0.0656	102.6543	0.2092
	P03	-0.1322	103.8326	0.2889
	P04	-0.1063	97.6855	0.5096
	P05	0.0537	105.8276	0.3046
	P06	0.0981	101.2130	0.2229
	P07	-0.0445	93.2050	0.0689
	P08	-0.1547	89.0195	0.5871
	P09	0.0148	91.2273	0.0346
15s	P01	0.0247	110.6847	0.0107
	P02	-0.0788	97.5056	0.5066
	P03	-0.0900	83.8973	0.1573
	P04	-0.0327	86.0838	0.0677
	P05	-0.0413	98.6469	0.2337
	P06	-0.0632	95.1155	0.2844
	P07	0.0526	90.1293	0.0661
	P08	0.0137	96.0839	0.0133
	P09	0.0359	94.7880	0.1773

Table 34: Results of the linear regression analysis of supraspinatus median power frequency over time

Condition	**Participant**	**Slope**	**Y-intercept**	**r^2**
120s	P01	-0.2467	98.7696	0.4828
	P02	-0.0341	96.0435	0.1858
	P03	0.0065	111.8254	0.0029
	P04	-0.0251	93.5606	0.0421
	P05	-0.0159	103.0912	0.0233
	P06	-0.2844	83.5266	0.3763
	P07	0.0123	99.0412	0.0105
	P08	0.0207	89.5966	0.0179
	P09	-0.1330	97.9028	0.5497
60s	P01	0.0102	106.3502	0.0048
	P02	-0.0242	95.6952	0.1009
	P03	-0.1440	94.8256	0.5823
	P04	-0.0511	96.6685	0.2153
	P05	0.0107	97.4463	0.0174
	P06	-0.0491	87.5644	0.1197
	P07	-0.1220	103.2891	0.4826
	P08	-0.0300	92.0883	0.0910
	P09	-0.0002	94.8735	0.0000
30s	P01	0.0230	92.2361	0.0235
	P02	-0.0411	96.0978	0.1845
	P03	-0.1160	101.7229	0.2967
	P04	0.0456	92.6293	0.2188
	P05	-0.0518	96.2271	0.1924
	P06	-0.1061	87.0635	0.2889
	P07	-0.1292	97.4393	0.3946
	P08	-0.1237	98.0231	0.4697
	P09	-0.0548	100.2266	0.3192
15s	P01	-0.0036	96.7231	0.0014
	P02	-0.1076	105.7874	0.6368
	P03	-0.1086	98.3223	0.3908
	P04	0.0297	95.8306	0.2047
	P05	0.0002	99.6719	0.0000
	P06	-0.0992	88.0307	0.2490
	P07	-0.0858	97.9365	0.3831
	P08	-0.0038	95.3374	0.0024
	P09	-0.0278	89.5386	0.1211

Table 35: Results of the linear regression analysis of middle trapezius median power frequency over time

Condition	Participant	Slope	Y-intercept	r^2
120s	P01	-0.1497	100.4028	0.2678
	P02	-0.0193	96.5457	0.0779
	P03	0.0365	99.1049	0.2032
	P04	-0.0228	100.1499	0.0606
	P05	-0.0673	86.3187	0.2219
	P06	-0.0316	95.7022	0.0160
	P07	-0.0360	92.6253	0.0746
	P08	0.0406	96.0322	0.1045
	P09	-0.0109	98.9912	0.0130
60s	P01	0.0538	95.5588	0.1877
	P02	-0.0234	90.8049	0.0999
	P03	-0.1193	101.8829	0.3580
	P04	-0.0622	97.9499	0.2611
	P05	0.0300	95.4080	0.1150
	P06	-0.0886	95.6405	0.4176
	P07	-0.1094	102.9933	0.5991
	P08	-0.0222	97.6076	0.0801
	P09	0.0114	96.9996	0.0174
30s	P01	-0.0209	92.9545	0.0209
	P02	-0.0192	95.8211	0.0691
	P03	-0.1567	106.8817	0.4902
	P04	-0.0218	88.7939	0.0596
	P05	-0.0362	105.3367	0.1547
	P06	-0.0400	94.4961	0.0623
	P07	-0.0804	91.0830	0.1954
	P08	-0.1234	95.1173	0.3876
	P09	-0.0065	99.0409	0.0095
15s	P01	-0.0510	101.4736	0.2209
	P02	-0.0721	107.2737	0.4027
	P03	-0.0098	102.7960	0.0039
	P04	0.0050	93.9457	0.0123
	P05	-0.0590	102.5180	0.4240
	P06	-0.0276	92.1387	0.0609
	P07	0.0115	90.0124	0.0046
	P08	-0.0272	96.1826	0.1999
	P09	0.0229	97.6756	0.1653

Table 36: Results of the linear regression analysis of upper trapezius median power frequency over time

Condition	Participant	Slope	Y-intercept	r^2
120s	P01	-0.1001	101.1292	0.1536
	P02	-0.0196	99.2182	0.0884
	P03	-0.0606	94.0465	0.3676
	P04	-0.0114	93.3979	0.0273
	P05	-0.0158	101.8097	0.0191
	P06	-0.1824	91.6668	0.3492
	P07	-0.0435	97.4125	0.1151
	P08	0.0367	92.9419	0.0834
	P09	-0.0536	100.9126	0.1412
60s	P01	0.1157	90.7625	0.3386
	P02	-0.0313	94.0719	0.1644
	P03	-0.0942	92.6076	0.4398
	P04	-0.0326	97.8821	0.0725
	P05	0.0000	92.8449	0.0000
	P06	-0.0862	96.1208	0.4405
	P07	-0.0424	108.4768	0.0837
	P08	-0.0113	94.9779	0.0151
	P09	-0.0255	94.4253	0.0734
30s	P01	0.0511	82.3116	0.0641
	P02	-0.0194	96.2885	0.0874
	P03	-0.1081	99.5479	0.3620
	P04	0.0368	93.9602	0.1556
	P05	0.0212	105.3374	0.0668
	P06	-0.0580	91.7884	0.1748
	P07	-0.1265	97.3585	0.5675
	P08	-0.1285	98.2262	0.3476
	P09	-0.0307	100.8246	0.1936
15s	P01	-0.0591	101.4925	0.3159
	P02	-0.0586	106.9815	0.2992
	P03	-0.1010	97.4060	0.3504
	P04	-0.0016	97.5260	0.0010
	P05	-0.0002	101.0726	0.0000
	P06	-0.0511	93.7963	0.0999
	P07	-0.1110	99.8345	0.5252
	P08	-0.0298	91.8031	0.1161
	P09	-0.0385	93.7623	0.2239

Table 37: Results of the linear regression analysis of anterior deltoid root mean square amplitude over time

Condition	Participant	Slope	Y-intercept	r^2
120s	P01	0.2294	139.3614	0.0624
	P02	-0.0550	100.2002	0.0824
	P03	-0.0838	132.8791	0.0450
	P04	-0.2319	106.8383	0.4204
	P05	0.0940	85.5033	0.2232
	P06	0.1171	102.2873	0.0155
	P07	0.8275	127.6902	0.5981
	P08	0.2354	100.9394	0.3609
	P09	0.0230	141.4626	0.0010
60s	P01	0.1344	103.2067	0.0173
	P02	-0.0317	98.2059	0.0394
	P03	-0.2404	108.2550	0.4862
	P04	-0.1342	92.8756	0.2222
	P05	-0.0965	94.3941	0.1543
	P06	0.0400	100.7305	0.0098
	P07	0.2768	128.9506	0.1186
	P08	0.0418	85.5146	0.0179
	P09	0.1086	110.5856	0.1366
30s	P01	-0.0325	115.4676	0.0069
	P02	-0.1415	132.7799	0.3323
	P03	-0.2672	124.6518	0.4294
	P04	-0.1400	101.0227	0.1210
	P05	0.0094	90.8957	0.0031
	P06	-0.3922	87.7989	0.5981
	P07	0.4151	134.7047	0.1902
	P08	0.1014	99.3120	0.0501
	P09	-0.0520	106.7609	0.0591
15s	P01	0.0734	120.9812	0.0156
	P02	-0.3459	170.4796	0.2392
	P03	0.2322	84.8902	0.3180
	P04	-0.1027	83.6641	0.1877
	P05	0.1042	113.8381	0.1667
	P06	0.3533	94.9740	0.0796
	P07	0.5271	81.9437	0.3235
	P08	0.0218	95.6974	0.0147
	P09	0.0848	109.8190	0.1470

Table 38: Results of the linear regression analysis of middle deltoid root mean square amplitude over time

Condition	**Participant**	**Slope**	**Y-intercept**	**r^2**
120s	P01	0.4069	129.6356	0.1617
	P02	0.1029	117.6092	0.1648
	P03	0.3945	168.0523	0.2208
	P04	-0.0403	131.0196	0.0226
	P05	0.2167	128.1406	0.1420
	P06	1.1573	146.0864	0.3705
	P07	0.6348	184.2950	0.2107
	P08	0.6985	143.3235	0.5968
	P09	0.2623	142.2673	0.2323
60s	P01	-0.0035	109.0735	0.0001
	P02	0.2490	106.6028	0.5851
	P03	0.1188	130.8582	0.0311
	P04	0.0018	100.0991	0.0001
	P05	-0.1423	127.6289	0.1369
	P06	-0.1450	124.4512	0.1745
	P07	0.0721	159.6804	0.0053
	P08	0.3367	138.4281	0.3736
	P09	0.0537	135.7261	0.0251
30s	P01	-0.5986	142.3329	0.5440
	P02	-0.1148	116.1876	0.1898
	P03	0.0604	122.6745	0.0207
	P04	-0.1543	106.8453	0.2835
	P05	-0.1954	127.0678	0.5544
	P06	0.0444	109.4209	0.0360
	P07	-0.6624	215.6506	0.1849
	P08	0.4115	93.3219	0.5873
	P09	0.0966	106.3344	0.2775
15s	P01	-0.1025	80.7554	0.2184
	P02	0.2073	113.8717	0.5324
	P03	1.2843	138.0171	0.8397
	P04	0.0377	90.3416	0.0266
	P05	-0.2857	131.5145	0.5508
	P06	-0.1196	154.9339	0.0309
	P07	-0.3275	188.1586	0.1194
	P08	0.3110	116.0579	0.7181
	P09	0.0628	116.2059	0.1256

Table 39: Results of the linear regression analysis of posterior deltoid root mean square amplitude over time

Condition	Participant	Slope	Y-intercept	r^2
120s	P01	1.4542	147.9156	0.4968
	P02	0.3730	207.5456	0.2059
	P03	0.3239	143.8988	0.2379
	P04	0.4439	207.7615	0.1538
	P05	-0.0037	129.4081	0.0001
	P06	1.7640	162.2933	0.4424
	P07	0.6697	174.0736	0.2700
	P08	0.5402	174.4269	0.1547
	P09	0.1171	174.3450	0.0126
60s	P01	-1.4626	381.7912	0.1584
	P02	0.2625	131.8320	0.3418
	P03	-0.1894	104.3161	0.2159
	P04	0.1826	128.4770	0.0944
	P05	-0.3097	118.6859	0.3095
	P06	0.0694	131.2735	0.0256
	P07	0.0001	161.3364	0.0000
	P08	0.0024	136.8608	0.0000
	P09	0.1845	144.6317	0.1869
30s	P01	-1.8631	267.3446	0.4674
	P02	0.0631	128.0736	0.0801
	P03	-0.1997	90.9468	0.2103
	P04	0.4294	100.6437	0.3723
	P05	-0.2476	139.9668	0.3488
	P06	0.0222	143.7006	0.0013
	P07	-0.0872	166.0548	0.0097
	P08	0.1268	98.3121	0.0605
	P09	-0.0604	74.7103	0.0848
15s	P01	-0.1915	85.8564	0.3844
	P02	0.4036	143.5997	0.5921
	P03	1.4275	122.8843	0.8458
	P04	0.1532	155.1690	0.0208
	P05	0.1259	126.1214	0.1694
	P06	-0.2293	169.9622	0.0612
	P07	-0.2752	150.9997	0.1788
	P08	0.1627	113.4167	0.2691
	P09	0.0367	95.6862	0.0205

Table 40: Results of the linear regression analysis of infraspinatus root mean square amplitude over time

Condition	**Participant**	**Slope**	**Y-intercept**	**r^2**
120s	P01	0.4348	144.7891	0.0778
	P02	0.0067	109.9703	0.0009
	P03	0.1593	110.4238	0.2164
	P04	-0.0419	106.5449	0.0222
	P05	0.0559	74.9078	0.0345
	P06	-0.0756	121.5780	0.0151
	P07	-0.0184	103.5430	0.0029
	P08	0.1357	114.5054	0.0973
	P09	-0.1921	119.5734	0.4281
60s	P01	0.1380	116.3969	0.0381
	P02	0.0356	106.5070	0.0422
	P03	-0.0709	90.6833	0.1204
	P04	-0.1232	95.0933	0.1765
	P05	-0.1859	96.4504	0.5384
	P06	-0.2719	131.7245	0.4109
	P07	-0.4812	102.3756	0.5285
	P08	0.0441	96.1358	0.0333
	P09	0.0158	113.6478	0.0090
30s	P01	0.1889	63.7811	0.1061
	P02	-0.1359	119.8929	0.3582
	P03	0.0437	108.0980	0.0162
	P04	0.4914	81.2417	0.7142
	P05	-0.1552	120.2459	0.2998
	P06	-0.3334	113.7572	0.5779
	P07	-0.1544	95.0066	0.0889
	P08	-0.7606	145.8061	0.4853
	P09	-0.0032	109.6529	0.0004
15s	P01	0.0340	161.0035	0.0022
	P02	-0.0013	95.8110	0.0001
	P03	-0.0327	89.2466	0.0254
	P04	0.0781	105.7720	0.0676
	P05	0.3121	166.1257	0.1882
	P06	-0.3815	105.3308	0.5760
	P07	0.5292	78.4177	0.2549
	P08	-0.1381	100.8738	0.1890
	P09	0.0702	93.1267	0.1926

Table 41: Results of the linear regression analysis of supraspinatus root mean square amplitude over time

Condition	Participant	Slope	Y-intercept	r^2
120s	P01	0.4143	123.3724	0.3097
	P02	0.2122	112.9384	0.4143
	P03	0.3995	148.4688	0.4043
	P04	-0.1339	105.7796	0.4262
	P05	0.3588	110.9185	0.2256
	P06	-0.4560	73.6960	0.3570
	P07	0.4580	123.6753	0.3788
	P08	0.1223	99.8156	0.1586
	P09	-0.0806	129.4031	0.0638
60s	P01	-0.5419	144.0240	0.3741
	P02	0.0292	124.1800	0.0161
	P03	0.0681	130.3615	0.0137
	P04	-0.0805	113.0349	0.0665
	P05	-0.1400	93.8017	0.3840
	P06	-0.1818	90.9600	0.6455
	P07	0.5099	128.2342	0.4153
	P08	-0.0389	90.4231	0.0639
	P09	0.1924	114.5050	0.4195
30s	P01	-0.4852	87.6215	0.6748
	P02	0.0480	116.7978	0.0560
	P03	0.1203	107.9275	0.0970
	P04	-0.0189	90.8629	0.0066
	P05	-0.1909	89.1974	0.5288
	P06	-0.0713	91.0654	0.0702
	P07	-0.0136	139.6345	0.0003
	P08	-0.2062	93.1868	0.5749
	P09	0.1084	88.6946	0.3901
15s	P01	-0.0575	306.3424	0.0010
	P02	-0.0901	98.8105	0.1958
	P03	0.0351	123.1033	0.0062
	P04	-0.2158	101.3320	0.6102
	P05	0.1261	142.3178	0.1389
	P06	-0.1754	104.3391	0.2376
	P07	0.1890	107.8131	0.2430
	P08	0.1158	100.8141	0.3045
	P09	0.0893	102.8251	0.3232

Table 42: Results of the linear regression analysis of middle trapezius root mean square amplitude over time

Condition	Participant	Slope	Y-intercept	r^2
120s	P01	0.6780	144.8808	0.2399
	P02	0.1147	134.4300	0.1691
	P03	0.0618	129.6901	0.0343
	P04	0.1162	140.5059	0.0354
	P05	0.1896	178.1153	0.0487
	P06	0.1009	107.3460	0.0293
	P07	1.0975	180.2475	0.3722
	P08	0.5360	134.6547	0.5754
	P09	0.0694	152.5405	0.0158
60s	P01	-0.2548	143.0022	0.1230
	P02	0.1182	106.9337	0.1878
	P03	-0.0562	113.4310	0.0132
	P04	-0.1285	124.0252	0.0652
	P05	-0.2220	97.8939	0.2552
	P06	-0.0457	124.1585	0.0217
	P07	0.4729	163.9303	0.1566
	P08	0.0035	104.2164	0.0002
	P09	0.3694	142.4933	0.3604
30s	P01	0.2772	73.5456	0.3578
	P02	0.0561	117.0855	0.1245
	P03	0.6064	124.0432	0.6561
	P04	1.1589	108.0226	0.5419
	P05	-0.2125	132.0948	0.2930
	P06	-0.2034	112.5654	0.4184
	P07	-0.3350	222.9306	0.0336
	P08	-0.2409	112.8476	0.2161
	P09	-0.1946	127.6153	0.2053
15s	P01	0.0207	142.1166	0.0010
	P02	0.1862	110.9765	0.4463
	P03	0.4086	121.6926	0.3716
	P04	-0.1488	103.7269	0.2240
	P05	0.0138	167.2217	0.0009
	P06	-0.2062	121.8661	0.1467
	P07	-0.3784	191.7998	0.1307
	P08	0.0186	122.1976	0.0065
	P09	0.3864	162.8662	0.3958

Table 43: Results of the linear regression analysis of upper trapezius root mean square amplitude over time

Condition	Participant	Slope	Y-intercept	r^2
120s	P01	0.6723	134.9326	0.3509
	P02	0.1190	109.3488	0.2427
	P03	0.2247	139.0120	0.2643
	P04	-0.0734	115.4485	0.0740
	P05	-0.1940	182.7063	0.0562
	P06	-0.3928	97.4676	0.4428
	P07	0.4065	116.0782	0.4365
	P08	0.1459	98.1304	0.2230
	P09	-0.0254	119.6162	0.0121
60s	P01	0.2830	97.5408	0.2694
	P02	0.0866	120.8090	0.1229
	P03	-0.1414	106.0567	0.1095
	P04	0.0075	118.4981	0.0003
	P05	-0.1017	92.8537	0.1887
	P06	-0.0828	114.5829	0.1361
	P07	0.9120	137.6646	0.6226
	P08	0.2014	109.7684	0.3773
	P09	0.1584	102.6992	0.3580
30s	P01	0.4484	59.3117	0.4108
	P02	-0.0125	112.7971	0.0040
	P03	-0.0204	105.4931	0.0047
	P04	0.0240	89.1503	0.0071
	P05	-0.0664	107.2594	0.0593
	P06	-0.1094	96.7549	0.1752
	P07	0.1465	144.8454	0.0290
	P08	-0.1185	103.6413	0.1374
	P09	0.3654	107.6029	0.8094
15s	P01	-0.2178	118.3356	0.2334
	P02	0.3695	85.9271	0.3996
	P03	0.2484	117.2516	0.2432
	P04	-0.1093	96.5748	0.2705
	P05	0.0487	131.6877	0.0306
	P06	-0.2022	119.2732	0.1496
	P07	0.1576	127.5213	0.1278
	P08	-0.0142	102.8371	0.0107
	P09	0.2264	107.0099	0.7206

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