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TITLE PAGE:

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Quantification of the safe maximal lift in functional capacity evaluations: comparison of muscle recruitment using SEMG and therapist observation

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Abstract.

Purpose: This study aimed to identify any correlation between muscle activity using surface electromyography (SEMG) and therapist determined safe maximal lift (SML) during the bench to shoulder lift of the WorkHab FCE. This would support construct (convergent) validity of SML determination in the WorkHab FCE.

Method: An experimental laboratory based study design was used. Twenty healthy volunteers performed the bench to shoulder lift of the WorkHab FCE whilst SEMG of upper trapezius, mid deltoid, thoracic, brachioradialis and bicep muscles were recorded. A summary of the data is presented using descriptive statistics and differences between groups were tested using generalised linear mixed models.

Results: Results showed a significant difference in activity and duration of muscle activation with increasing weight lifted ($p=0.000$ and $p=0.024$(brachioradialis)). There was a significant difference between the up lift (bench to shoulder) and the down lift (shoulder to bench) for all muscles ($p=0.000$) except the brachioradialis ($p=0.819$). No significant change was found in muscle activity before or after the SML.

Conclusions: Convergent validity of the bench to shoulder lift of the WorkHab FCE was not established as no relationship between the muscle recruitment using SEMG and SML, as determined by therapist observation was identified during this lift.

Keywords: Electromyography, Lifting, Work capacity evaluation, WorkHab FCE.

1. Introduction

Functional capacity evaluations (FCEs) are standardised assessments that are used in occupational and vocational rehabilitation as performance measures to make decisions about the capacity of a worker in relation to their work abilities [1]. FCEs are used to screen potential employees as pre-employment assessments, to assess physical rehabilitation needs, to determine work readiness and job placement following injury, to facilitate return to work and to determine a person's functional capacity for compensation or litigation reasons. They are designed to define the functional abilities and limitations of an individual in the context of safe, productive work tasks and are commonly used with individuals who have suffered work related musculo-skeletal injuries [2-7]. One of their uses is to evaluate a person's manual handling capacity to establish the amount that they can safely lift – the safe maximal lift. There are many different types of FCEs used commercially [8], and they are used in a variety of practices [9-14, 2].

Lifting requires the coordination of multiple neuromuscular components [15] and many factors may affect the way a person completes a lift. These include the magnitude and shape of the load, joint angles during the lift, the muscles activated during the lift and the speed at which the lift is completed. Factors that alter kinematics during lifting tasks can cause an increase in joint stress [16, 17], affect the ability to balance during the lift [18] and may impact upon the risk of injury [19, 20] which is of particular importance when considering a person's lifting or manual handling ability post workplace injury.

Lifting is one component of an FCE. When completing FCE's practitioners use a variety of theoretical knowledge to inform this process, these include the biomechanical, physiological, metabolic, psychophysical and kinesiophysical approaches, each differing in its focus [21, 22]. When an evaluator uses the psychophysical approach control is placed upon the participant, so it is the participant who decides when to terminate the test thereby determining maximum function [22, 23, 21]. This was cited as the primary model used in FCE practice in an Australian study in 1997 [22], however issues with injured participants determining their own safe limits have been identified. On the other hand, the kinesiophysical model utilises observation of movement patterns (biomechanics) and physiological performance to evaluate safe maximum function [24] and the evaluator focuses on the person's physiological responses and adaptations to workload. Using the kinesiophysical model it is the evaluator who controls the test by monitoring for physiological maximal capacity.

The WorkHab FCE is commonly used in the Australian occupational rehabilitation environment [9, 13, 25, 10] and is based on the objective physiological measure of heart rate, observations of physiological signs, observations of biomechanics, reported pain and ratings of client perceived exertion (effort). The kinesiophysical approach is used with the evaluator observing physiological signs and biomechanical movement patterns to determine a safe maximal lifting (SML) load [26].

Surface electromyography (SEMG) (the use of surface electrodes to record electrical potentials from underlying muscles [27]) has been used to measure muscular activity in a broad range of settings. In studies of occupational musculoskeletal disorders, SEMG has been used to quantify exposure or fatigue in different environments or with different equipment [28-33] .

Evidence of psychometric properties of specific FCE tools has been lacking, despite the need for health professionals to use evidence to support interventions. This has been achieved in part for some commercially available FCE tools [34, 35, 8, 36, 37, 2]. This study was completed to provide evidence of the validity of the bench to shoulder lift in the WorkHab FCE. The aim of this experimental study was to identify if there was any change in muscle activity, as determined by SEMG that corresponded with the safe maximal lift as determined by therapist observation during the bench to shoulder lift of the WorkHab FCE. This study aimed to identify if two measures (muscle activity (SEMG) and therapist determined SML) believed to reflect the same phenomenon are highly correlated [38]. This was undertaken to support construct validity, specifically convergent validity of this assessment tool, specifically in relation to SML determination and also aimed to identify if there was a relationship between muscle activity and increasing weight lifted during the bench to shoulder lift of the WorkHab FCE.

2. Methods

2.1. Sample

Ethical clearance was obtained from the University Human Research Ethics Committee, following which subjects were recruited using posters to advertise the study and via an email sent from the School of Health Sciences office to staff and students at the University, inviting participation. Interested persons contacted the researcher directly to discuss the study, receive an information statement and subsequently arrange an assessment time. A convenience sample of 20 healthy adult volunteers was recruited.

2.2. Study design

This study used a laboratory based, experimental design. Participants completed the bench to shoulder lift of the WorkHab FCE.

The procedure for the manual handling component of the WorkHab FCE uses a modular box system, which allows boxes to be stacked at various heights. Each lift is fully explained and demonstrated to the subject prior to commencement. Boxes are set at an appropriate height, and the subject is instructed to lift the load box (initially empty) from beginning to end height and return. This is repeated three times before additional weight is added to the load box. The FCE assessment uses a protocol of increasing load at each height until the safe maximum lifting limit is reached. Baseline heart rate is taken initially and then readings are taken after each three lift set to review the subjects' heart rate, using a heart rate monitor worn throughout the assessment. This is to monitor that heart rate does not exceeds predetermined levels of age predicted maximal heart rate [39, 26].

In this experimental study the height of the lift was relative to the subject's waist (for the bench component) and shoulder (for the shoulder component). This lift was chosen for practical reasons of access to the EMG and WorkHab FCE equipment and for clarity of video recording for expert panel rater assessment. The lifting protocol was explained to participants and they were instructed to lift with weight being increased incrementally in 2kg amounts. Incremental increases in weight were used for each participant to track changes in muscle recruitment using SEMG, as weight increased. Participants were instructed to lift until they perceived they had reached their maximum abilities and could not lift anymore weight. The WorkHab accredited assessor observed the lifting, asked participants if they wished to complete another lift with each additional weight and monitored for excessive heart rate, however in this study they did not influence participants when to cease lifting.

Prior to commencing the FCE, each subject gave informed consent and signed a consent form. Each subject completed a pre-assessment screening, including: completion of a questionnaire to determine medical status; measurement of height and weight and a blood pressure check, to determine any medical risks and to screen for current injuries. Participants' muscles were palpated, skin prepared by shaving, abrading with sandpaper and cleaned with alcohol before disposable, self-adhesive, surface electrodes (ADInstruments: MLA1010) were positioned parallel and either end of the muscle bulk of the brachioradialis, bicep, mid deltoid and upper trapezius muscles on the left side of the body, and, approx. 2cm from the spinous process at the level of T6 and T9 for the thoracic paraspinal muscles. A single researcher trained in physiotherapy and manipulation skills marked each participant to minimise variation.

2.3. Data collection

Participants were video-taped using two Sony Handycam Camcorders (Model HRD-HC9E, Sony, Tokyo, Japan). The camera images were recorded digitally using Dartfish Pro-Suite (Dartfish, Lausanne, Switzerland) and were set up to view the rear coronal and right sagittal planes during lifting.

An ADI Powerlab 8SP (ML 785, ADInstruments.com) in combination with a tower of four dual bioamplifiers (ML135) was used to collect surface electromyography data and transmit to a laptop for processing. LabChart software (version 7.1.2, ADInstruments.com) using a windows XP operating system was used to process the SEMG signal.

2.4. Measurements

Maximal isometric voluntary contractions (MVC) were recorded for each muscle as a reference. Three resisted maximum voluntary contractions of 6 seconds each were recorded for each muscle. For the thoracic spine the participant laid prone, shoulders were abducted to 90º, elbow flexed to 90º, and pressure applied to the trunk at level T12/L1 as the participant was instructed to raise their arms and head in one movement into the ‘aeroplane’ position. MVC for the upper trapezius was recorded with resisted elevation of the shoulders. For the mid deltoid, the participant abducted the shoulder to 90º and was resisted at the wrist whilst trying to adduct the shoulder. The MVC for the biceps muscle was recorded with the elbow held at 90º flexion, resistance was applied at the wrist and stabilisation of the upper arm occurred whilst the participant attempted to flex the elbow. With the elbow flexed to 90°, forearm in neutral position and upper arm close to body, the participant was resisted in radial deviation to record the MVC of the brachioradialis muscle.

SEMG recordings were taken for each set of three lifts (at one weight) at a sampling rate of 1k/s with high (minimum cut off 0.3Hz) and low pass (maximum cut off 1kHz) filters. Following data collection, the raw data for each muscle was normalised and rectified using the LabChart (v7.1.2) software.

The computer software collected the following data: Root-mean-square (RMS) of the raw data in mV, the integral of the RMS trace in mVs, mean power frequency of the raw data in Hz and duration in seconds for each set of 3 lifts at each weight. For each lift up (from bench onto the shoulder height box) and down (from the shoulder height box to the bench) the mean of RMS, integral, power and duration was calculated from the 3 lifts at each weight and used for data analysis. To aid comparison of muscle activity between individuals, the RMS values were normalised and expressed as a percentage of the maximum voluntary contraction.

The video of each participant completing the lifting segment was de-identified and a focus group of five expert therapists who met the inclusion criteria of being WorkHab FCE accredited therapists with a minimum of 5 years FCE experience, evaluated the videos. The experts included five occupational therapists (four female and one male) with a mean of 10.5 years professional experience (SD: 4.3) and 8.3 mean years of FCE experience (SD: 1.7). The focus group was facilitated by an expert in focus group methodology who was not a therapist familiar with FCE's. Focus groups engage groups of individuals with similar characteristics [40] and allow for interaction between professionals with facilitated explanations of practices, beliefs and attitudes [41]. The use of experts as part of assessment validation is well documented [42, 38]. The video data of the manual handling component of the WorkHab FCE was viewed and individually each expert identified the lift they considered the safe maximal lift for each of the 20 healthy subjects, using the WorkHab FCE protocol. The results for each subject, from each member of the expert panel, were then collated to determine any agreements or disagreements in SML determination. Facilitated discussion then took place to reach a consensus on the SML for each subject. This point was used during analysis of the SEMG data.

2.5. Data analysis

Descriptive statistics were used to describe the participants and to provide means and standard deviations of muscle activity. The mean of RMS, integral, power and duration was calculated from the 3 lifts at each weight and used for data analysis. To aid comparison of muscle activity between individuals, the RMS values were normalised and expressed as a percentage of the maximum voluntary contraction. A generalised linear mixed model with a random intercept for the individual was used to analyse the SEMG data for the last five lifts for each participant. This model was chosen as we had repeated measures on the same individual, and the random intercept model adjusts for clustering of observations within individuals. This analysis aimed to identify any SEMG factors that were associated with the SML. All statistical analyses were performed using the statistic package STATA V11.1 [43].

3. Results

3.1. Participants

The study sample consisted of 10 women and 10 men ranging in age from 21 years to 64 years, with a mean age of 39.5 years (SD 14.8)**.** The participants lifted a mean weight of 20.45kg (SD: 5.44, Range: 13kg to 35kg). Each participant commenced lifting with an empty box of 7kg. Weight was incrementally increased in 2kg loads, and the number of incremental increases in weight ranged from 5 lifts to 16 lifts.

3.2. Relationship of muscle activity and increased weight

The time of muscle activation at the different lift weights is shown in Figure 1. In most muscles there is an incremental rise in the time of muscle activation with increasing weight lifted. The exception is the upper trapezius muscle where lift 3 saw a sharp increase in time of activation. However, when this data was analysed using regression, there was no significant difference in time of muscle activation between lifts 1, and 2, 3 or 4 for all muscles but a significant difference in time of muscle activation was found between lift 1 and 5: Upper Trapezius (p=0.006); Mid Deltoid (p=0.002); Thoracic (p=0.005); Brachioradialis (p= 0.024) and Biceps (p=0.0005).

Insert Figure 1

In all participants, muscle activity showed a linear relationship with weight. The greater the weight being lifted the higher the muscle activity as is shown in the group mean RMS scores as a percentage of the maximum voluntary contraction for each muscle in Figure 2. The change with weight was significant in all muscles as can be seen in Table 1.

Insert Figure 2

3.3. Safe maximal lift, lift up, lift down and weight

Table 1 outlines the variations in muscle activity between lifting the load up (from bench onto the shoulder height box) and down (from the shoulder height box to the bench) for each muscle. There was a significant difference in muscle activation, between the up lift and the down lift for all muscles except the brachioradialis (p=0.819). Weight was used as a continuous predictor variable in this analysis and therefore the coefficient reported in Table 1, indicates the change in RMS associated each one unit increase in weight, for example, in the Upper Trapezius, each one unit increase in weight is associated with an average increase in RMS of 0.15. However, a correlation between muscle activity and the SML was unable to be established as no significant difference was found in muscle activity (RMS, Integral, power, or RMS as a percentage of MVC) before the SML as determined by the expert panel, and after the SML in any of the muscles studied.

Insert Table 1 here

4. Discussion

This study demonstrated that there was an increase in muscle activity as determined by SEMG with increasing weight during the bench to shoulder lift of the WorkHab FCE. Other studies investigating the effect of load have also found increasing levels of muscle activity with increased load [44-46]. Incremental weight increases were used in this study which may account for the linear increase identified in the muscle activity levels. The properties of the SEMG signal are related to the biochemical and physiological changes in skeletal muscles during fatiguing contractions. In this study participants completed repetitive lift segments, with weight being incrementally increased after each three lifts until they had reached their maximum abilities. The number of repetitions ranged between 5 and 15 lift segments or in real terms 15 to 45 actual lift repetitions. An increase in SEMG signal amplitude estimates such as that of the root mean square calculations have been linked with muscular effort and fatigue [47] as was also found in this study. There have been many studies investigating the effect of muscle fatigue in relation to manual handling and lifting [48-50, 47], with the results being well documented. The influence of fatigue on muscle activity is an aspect of ability that does need consideration when conducting endurance lifting activities as part of any FCE. Fatigue may however, also need to be considered with lifting tasks more generally if participants are completing many lifts to achieve a safe maximum. It is noted in a WorkHab FCE the weight lifted is not necessarily increased incrementally, as it was in this study, so as to reduce the number of lifts and therefore combat the impact of fatigue in determining a safe maximal lift.

A relationship between the weight (load) lifted and the subsequent load placed upon the spine has also been reported, during a work capacity assessment [44] and in studies investigating load on joints [51]. Frequency of lift has also been reported to impact upon muscle activity in both low back muscles and shoulder muscles [52]. Duration of muscle activation for each of the lifts in this study found an incremental increase in time with increased weight lifted overall. There was a significant increase between the lift with the lightest load and the lift with the heaviest load. Time to complete the lift (or muscle activation time) may be affected by the frequency of lift. Lift frequency was not considered in this study, as with the procedures for the WorkHab FCE, participants completed the lifts in their own time, with no imposed number of lifts per minute as have been considered in other studies [31]. However, the procedures for the WorkHab FCE do require the therapist to score the timing and pacing of lifting in relation to the smoothness and speed of movements as part of the manual handling score [26]. Further studies investigating the relationship between muscular activity time and weight in other lifts (bench to bench , bench to overhead or floor to bench) and with an injured population are needed to determine if the findings of increasing time with increasing weight is common across all lifting components of an FCE.

Changes in muscle activity in lifting up (ascending, bench to shoulder height) and down (descending, shoulder height to bench) with loads were found in this study, with the difference being significant in the upper trapezius, mid deltoid, thoracic and bicep muscles. Differences between ascending and descending lifts have also been identified in studies investigating muscle function during full squats with the ascending lifts showing an increased muscle activity level when compared to descending lifts [46] in most muscles. In this study there was no significant difference between the up phase and the down phase of the lift in the brachioradialis muscle which, as an elbow flexor muscle, may be the result of the elbows being flexed during both phases of the lift. The grip used during this lift may also have impacted upon the activity of the brachioradialis muscle. The WorkHab FCE uses load boxes with cut-out handles on the side of the box. The handle position dictates the hand grip needed to lift the box. The corresponding wrist position during the lifting phase may also impact upon the brachioradialis muscle activity levels and could account for the lack of difference between the ‘ascending’ and ‘descending’ lifts identified in this study. The presence of handles was found to have a significant difference on spinal loading in a study of the effects of box features during warehouse manual handling [53]. Another consideration is that despite the focus on the shoulder girdle, especially the upper trapezius muscle, in relation to lifting ability [33, 29, 54, 55], the forearm muscles could be a limiting factor, and this needs further exploration in relation to lifting during an FCE. A review of the biomechanics during the bench to shoulder lift would also indicate if joint position may affect the level of muscle activity and the lack of difference between the up phase and the down phase of the lift in the brachioradialis. Biomechanics play a significant role in lifting and it has been shown that altered biomechanics during lifting tasks can cause increased joint stress and an increased risk of injury [51].

In this study, there was no significant change in muscle activity between the lifts prior to the safe maximal lift (SML), as determined by the expert panel and the SML or lifts following. Safe maximal lift in the WorkHab FCE is determined based on monitoring heart rate and observation of biomechanical movement patterns however this study showed there was no relationship between the SML and the recorded SEMG parameters, hence no correlation was found between muscle recruitment and SML.

SEMG has been used to determine subject effort in a comprehensive muscular activity profile where it was used in conjunction with range of motion testing, as a predictor of whether a subject was performing at maximal or sub-maximal effort during FCE testing. This was compared to therapist ratings [56], with high levels of sensitivity demonstrated, which suggests this can be used as a method to identify muscular effort but this may not be linked to the determination of whether a lift is at the safe maximal level or not. The sensitivity and specificity of determining maximal effort was also studied by Lemstra et al, although this also looked at effort rather than safe maximal lift [57].

Safe maximal lifting limits have been proposed according to lifting height, frequency and worker characteristics [58] and when considering the compression force on the spine [59], however Cole found in his study of the loads on the spine during the work capacity assessment, the recommended limits were exceeded [44]. Differences between safe lifting limits were also reported when comparing FCE and the NIOSH guidelines [60]. The principles of safe manual handling techniques are used in the WorkHab FCE to determine the SML: a steady base of support; neutral spinal curves; loads kept close to the spine and within range of gravity where possible; no twisting; and movements that are smooth and controlled [26].

Observation of the recruitment of upper extremity strength for the ability to control the lift and the ability to stabilise the lumbo-sacral spine without hyperextension is suggested for the shoulder lift during the WorkHab FCE [26]. Other observations recommended for determination of SML include, muscle bulging of prime movers, involuntary use of accessory muscles, altered body mechanics including counterbalancing, loss of equilibrium, increased base of support, decreased efficiency and smoothness of movement, cardiovascular signs of heart rate and breathing patterns and referred symptoms [61]. An operational definition of safe lift used in a study by Gardener and McKenna advised that an unsafe lift included observation of extremes of trunk or upper limb range of motion, poor control of the load and/ or the load not kept close to the body [62].The end point of lifting in a waist to waist lift was reported as being mainly for biomechanical reasons particularly an increased lumbar lordosis in a study of the GAPP-FCE with persons with chronic low back pain [63]. Good reliability of determining the safe maximal lift during FCE’s has been reported [62, 61, 64-66], however this study was unable to identify any particular muscle recruitment marker (using SEMG) that correlated with the safe maximal lift as determined by assessors for the WorkHab FCE. Lifting capacity at different heights is affected by both aerobic capacity and strength [67], but it may also be determined by technique. Basic physiological measures did not explain the variability of individuals lifting capacity in a study of the determinants of a person’s safe maximal lift [68], which suggests technique, as is considered by the assessor in determining the SML for individuals during the FCE, may also contribute to the safe maximal lift.

The lack of significant change in muscle activity identified in this study at the point of the safe maximal lift suggests that biomechanical determinates are being used by therapists as part of the clinical reasoning process to clarify a SML and these do not necessarily correlate with particular muscle recruitment indicators. Further studies investigating the biomechanical changes during the bench to shoulder lift (and other lifts) are recommended to ascertain if there are quantifiable changes occurring that assist in the determination of a SML.

5. Limitations

One limitation of this study is that subjects were healthy individuals with no manual handling restrictions. Further studies on an injured population are needed to determine if these results are generalisable to that population. Another limitation relates to the use of the normalization technique employed for the SEMG data, which when completed allows data to be compared between individuals. The technique used in this study was to determine the MVC and then calculate the RMS as a percentage of the MVC. The use of MVC is commonly used in SEMG studies, however it is noted that this is an isometric contraction and is being compared to a dynamic activity. It has also been noted the ability to maximally activate motor units is dependent upon many factors such as motivation, training and the specific muscle activation, with reports that an MVC can be 20-40% less than the true maximum [69]. In this study a standardized procedure with a qualified physiotherapist was used to minimize this limitation.

6. Conclusions

This study identified that there was a significant relationship between the weight lifted and muscle activity in the upper trapezius, mid deltoid, thoracic, brachioradialis and biceps muscles during a bench to shoulder lift of the WorkHab FCE. The study identified that there was a significant difference between muscle activity in the up lift (bench to shoulder height) and the down lift (shoulder to bench height) in these muscles with the exception of the brachioradialis. However, no significant changes in muscle recruitment/ activity using SEMG were found before or after the safe maximal lift as identified by an expert panel of therapists. The quantification of the safe maximal lift in clinical practice requires further investigation with a suggested focus upon the biomechanical patterns of lifting during the FCE and the specific clinical reasoning processes used by therapists in practice. Quantification of a SML is not only needed within the FCE environment, but will also assist in recommendations for safe lifting practices, the training of workers in lifting and the design of tasks to reduce the burden of injury as a result of lifting activities.

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Figure 1: Lift time, muscle involvement and weight progression (N=20)

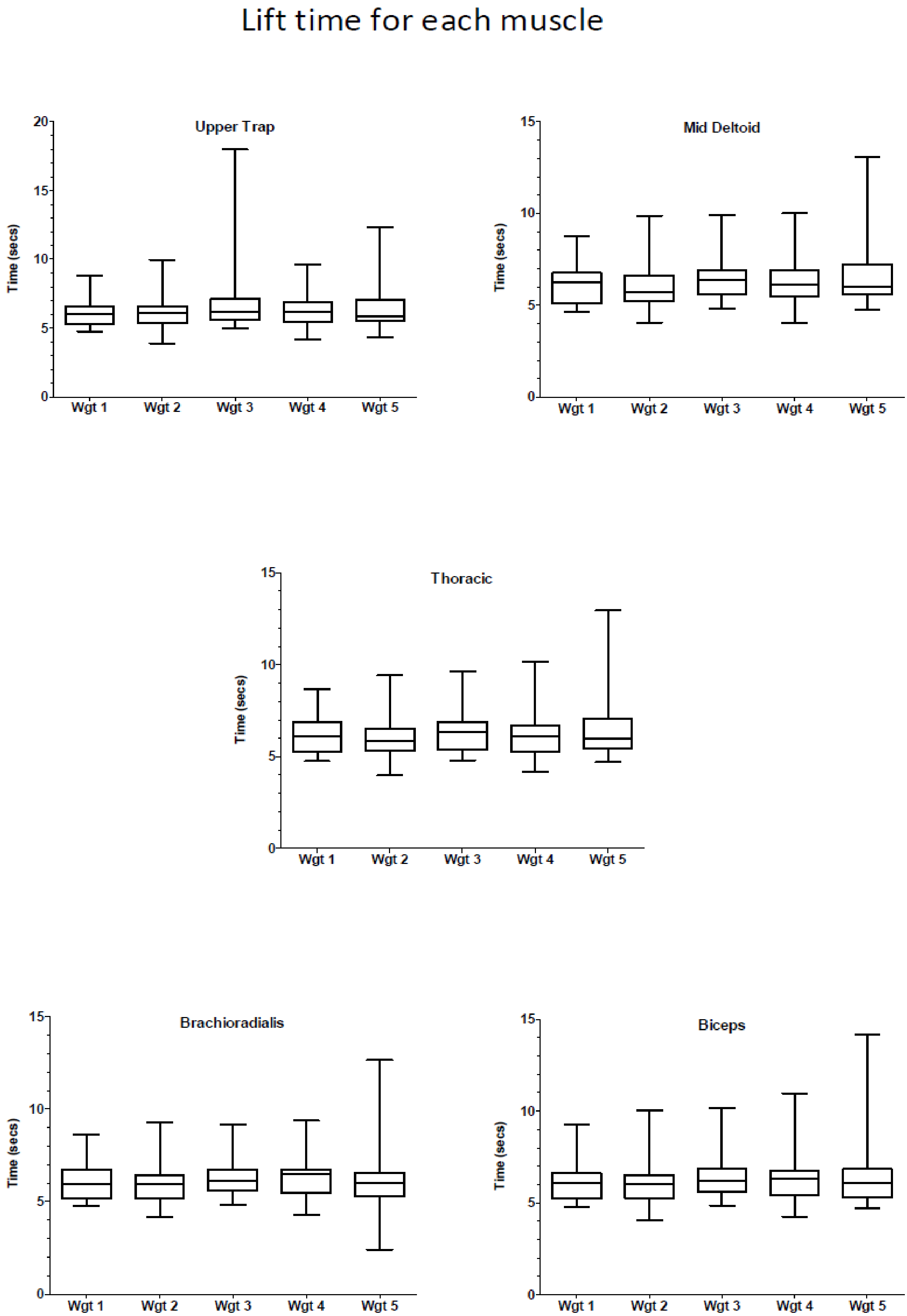

Figure 2: RMS as % of MVC for each muscle for each weight. (N=20)

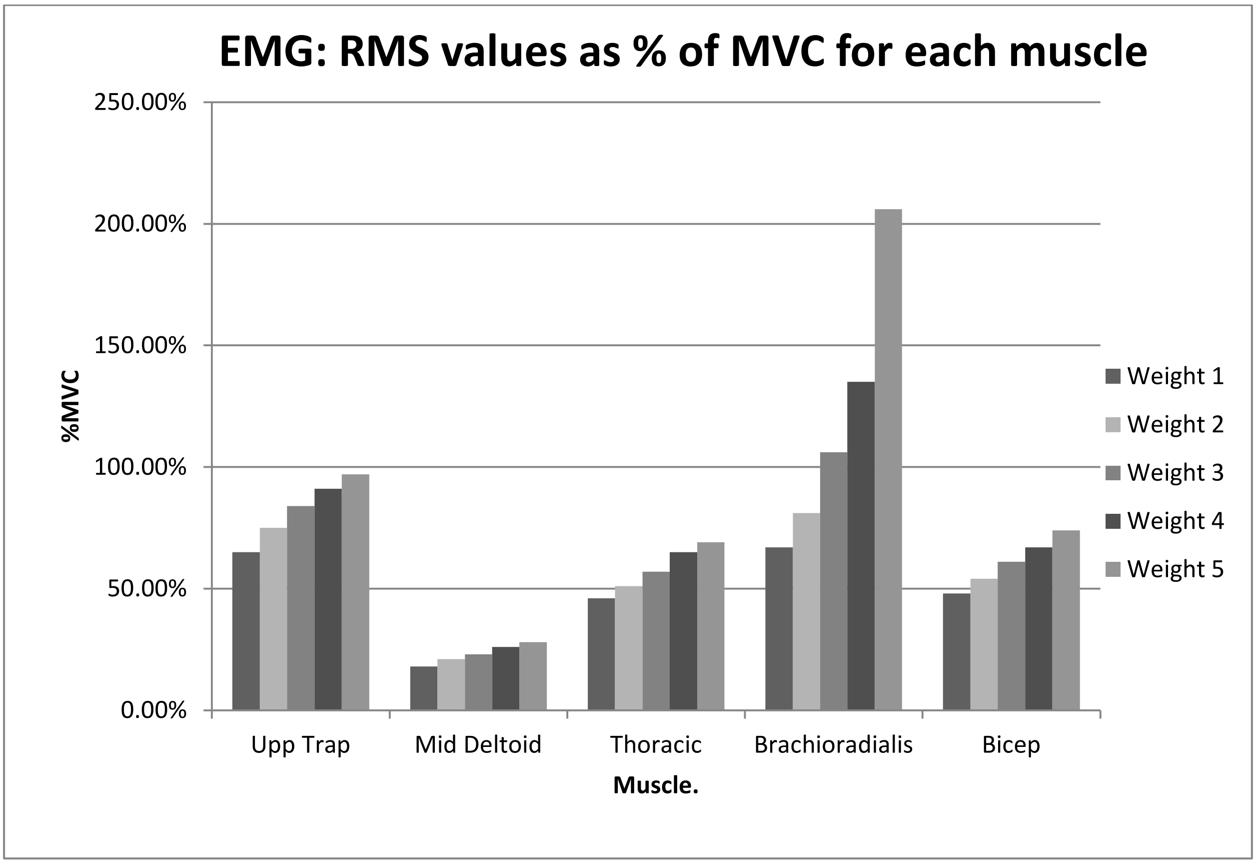

Table 1: Changes in muscles: lifting load up and down, before and after SML and with increasing weight (N=20)

Muscle	Lift up/down				Before and after SML				With increasing weight			
	Coef.	**St Err**	**CI**	**P-value**	**Coef.**	**St Err**	**CI**	**P-value**	**Coef.**	**St Err**	**CI**	**P-value**
Upper Trapezius	0.048	0.004	0.04:0.06	0.000	-0.001	0.006	-0.01:0.01	0.895	0.019	0.002	0.01:0.02	0.000
Mid Deltoid	0.031	0.002	0.02:0.03	0.000	-0.006	0.004	-0.01:0.002	0.146	0.014	0.001	0.01:0.02	0.000
Thoracic	0.079	0.014	0.05:0.11	0.000	0.0003	0.027	-0.53:0.05	0.989	0.592	0.008	0.04:0.07	0.000
Brachioradialis	0.049	0.204	-0.35:0.45	0.819	0.221	0.373	-0.51:0.95	0.555	0.275	0.122	0.03:0.51	0.024
Biceps	0.098	0.009	0.07:0.12	0.000	-0.006	0.0172	-0.04:0.02	0.704	0.064	0.005	0.05:0.07	0.000