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Evaluation of recommended maximum voluntary contraction exercises for back muscles commonly investigated in ergonomics

Saif K. Al-Qaisi[a], Alif Saba[a] and Ibrahim Alameddine[b]

[a]Industrial Engineering and Management, American University of Beirut, Beirut, Lebanon; [b]Department of Civil and Environmental Engineering, American University of Beirut, Beirut, Lebanon

ABSTRACT

Maximum voluntary contraction (MVC) exercises are commonly employed for normalizing electromyography (EMG) data to enable comparisons between different individuals and muscles. The purpose of this research was to test various recommended MVC exercises for two commonly investigated back muscles in ergonomics and, based on EMG results, determine the most appropriate exercise for each muscle. Through a preliminary review, these two muscles were identified as the lumbar erector spinae (LES) and thoracic erector spinae (TES). Fifteen healthy male participants were recruited. Five different recommended MVC exercises were performed for both muscles, including declined trunk extension, prone trunk extension, standing trunk extension, hip extension, and the arch test. Results showed that no single exercise was capable of eliciting the highest EMG amplitude in all the participants. The largest EMG average was reported using hip extension for the LES and prone trunk extension for the TES; however, no statistically significant differences were detected between them and other exercises, apart from declined trunk extension. Overall, the arch test showed the most favorable results for both the LES and TES, in that it: had a high EMG average; was the most consistent to elicit the highest EMG amplitude in participants; and had relatively low variability.

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Maximum voluntary contraction; normalization; electromyography; ergonomics; erector spinae

Relevance to human factors/ergonomics theory

This article addresses the discrepancy in the literature regarding the recommended maximum voluntary contraction (MVC) exercises for normalizing electromyography (EMG) data of the lumbar and thoracic erector spinae, two of the most frequently investigated back muscles in ergonomics. Using an accurate MVC for EMG-normalization is essential for maintaining the physiological benefit of this method, which translates EMG data from its bioelectrical nature into a biomechanics variable. Therefore, five different recommended MVC exercises were tested and compared to identify the exercises that elicit the highest EMG amplitudes for each muscle.

CONTACT Saif K. Al-Qaisi sa189@aub.edu.lb Industrial Engineering and Management, American University of Beirut, Beirut, 1107 2020 Lebanon.
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1. Introduction

Work-related musculoskeletal disorders (WMSDs) are prevalent across various occupations, affecting nursing assistants, janitors, stock clerks, repair workers, manual laborers, and among many other workers. Different factors have been associated with increasing WMSD risk. Some of the frequently cited include: physical factors such as forceful exertions, repetitive motions, frequent bending and twisting, and sustained postures; environmental factors such as cold temperatures and strong vibration; psychosocial factors such as high work load, low control, time pressure, and poor social support; and individual factors such as anthropometry, strength, and personality type (National Research Council and Institute of Medicine 2001; Radwin, Marras, and Lavender 2001; Gary Allread and Marras 2006; Sobeih et al. 2006; Nimbarte et al. 2012). Employers in the US are estimated to spend as much as $120 billion in direct and indirect costs for WMSDs (Occupational Safety and Health Administration 2014). The most commonly affected body region by WMSDs is the back, which accounted for 38.5% of WMSD cases in 2015 (Bureau of Labor Statistics 2018). Given the high injury rates and the associated costs, back WMSDs have been a major focus in the ergonomics literature.

Surface electromyography (EMG) has been commonly used in ergonomics for evaluating the causes and potential interventions for back WMSDs. The device offers a non-invasive method for directly assessing physical loads acting on a muscle by measuring its myoelectric activity, recorded in micro- or milli-volts (De Luca 1997). However, a necessary condition for EMG interpretation is to normalize raw EMG signals to a reference value (Ball and Scurr 2013; De Luca 1997; Lehman and McGill 1999). This is achieved by dividing the EMG data from a specific task (i.e. task-EMG) by the EMG from a reference contraction of the same muscle, reporting the data as a percentage of the reference value. Various normalization methods exist; yet the most widely used has been the maximum voluntary isometric contraction (MVC) method (Burden 2010; Knutson et al. 1994; Vera-Garcia, Moreside, and McGill 2010). The MVC involves performing an isolated single-joint maximal isometric exertion against a fixed resistance, seeking to elicit the muscle's maximal activation capacity (Al-Qaisi and Aghazadeh 2015). Burden (2010) endorsed the MVC method for its good reliability after reviewing eight different normalization techniques. In addition, the MVC method has an inherent advantage compared to other methods in that it provides information about the activation level of a muscle relative to its maximal physical capacity (Allison, Marshall, and Singer 1993; Allison, Godfrey, and Robinson 1998; Yang and Winter 1984). This form of normalization translates the EMG data from its bioelectrical nature into a biomechanics variable, expressed as a percentage of the muscle's MVC (Burden 2010; Mathiassen, Winkel, and Hägg 1995). Hence, ergonomics professionals have commonly used this method of normalization for its physiological relevance.

The challenge with the MVC is to select the appropriate MVC exercise that truly elicits the muscle's maximal physical potential. The literature generally presents various recommended MVC exercises for a particular muscle with no consensus on one exercise (Ekstrom, Soderberg, and Donatelli 2005; Kelly et al. 1996; Ng et al. 2002; Vera-Garcia, Moreside, and McGill 2010). If an inaccurate MVC is used for normalization, then the resulting EMG signals may at times exceed 100% MVC, incorrectly implying that the muscle is active beyond its maximum physical capacity (Burden 2010; Park and Yoo 2013). In such cases, the MVC method will actually be operating as a submaximal voluntary contraction

(sub-MVC) normalization technique, diminishing the inherent advantage of the MVC method. It is therefore essential that an accurate MVC is selected for normalization and maintaining the physiological benefit of this method.

Published MVC methods were reviewed with the aim of finding the most commonly used back muscles in the ergonomics literature with the hope of converging to one MVC exercise for each muscle. Through a preliminary review of 40 ergonomics studies (Appendix A, Supplemental material), this research identified the two most frequently used back muscles as the lumbar erector spinae (LES) (46%) and thoracic erector spinae (TES) (25%). These muscles represent the low and mid regions of the back, respectively.

The literature presents various recommended MVC exercises for both the LES and the TES, highlighting the lack of consensus on the most appropriate MVC exercise for each muscle. For both the LES and TES, the most explored exercise was found to be the maximal trunk extension against manual resistance while lying prone on a flat surface (Vera-Garcia, Moreside, and McGill 2010; Plamondon et al. 1999; Ng and Richardson 1994; McGill 1991; Jorgensen and Nicolasien 1986). It was reported to result in the highest EMG amplitude from both muscles (Vera-Garcia, Moreside, and McGill 2010; McGill 1991). Another exercise that elicited high EMG amplitudes was the maximal hip extension against manual resistance while lying prone on a flat surface (Vera-Garcia, Moreside, and McGill 2010). Ng and Richardson (1994) tested both of the aforementioned exercises in addition to a third exercise referred to as the prone ach test. The latter exercise showed even greater EMG amplitudes than the two other exercises. The prone arch test requires participants to lie prone on a flat surface and gradually hyperextend their upper trunks and hips upwards. Several earlier studies have supported the prone arch test as the most appropriate MVC exercise for the erector spinae muscles (Konrad 2005; Jonsson 1970; Pauly 1966). Other effective MVCs were variations of the trunk extension exercise, such as trunk extension while standing (McGill 1991; Jorgensen and Nicolasien 1986) and trunk extension on a declined surface (Plamondon et al. 1999). Plamondon et al. (1999) compared trunk extension on a 30° and 60° declined surfaces to a flat surface (0°). They found that the muscle activities of the erector spinae were greatest when trunk extension was performed starting at 60°. Callaghan, Gunning, and McGill (1998) reported that trunk extension exercises in general produced higher EMG activities in extensor muscles as compared to other exercises.

The lack of consensus on the MVCs for the LES and TES is largely due to the fact that previous studies considered limited or different sets of MVC exercises and therefore had different recommendations. A more comprehensive research that examines the recommended MVC exercises with respect to one another is much needed. Therefore, the purpose of this research was to test and compare the recommended MVC exercises for the LES and TES and identify the exercises that elicit the highest EMG amplitudes for each muscle.

2. Methods

2.1. Participants

Fifteen healthy university-aged male participants were recruited for this study. An orientation to the experimental procedures was provided to the participants, and their signatures were obtained on informed consent forms approved by the Institutional Review Board (IRB). The

Physical Activity Readiness Questionnaire (PAR-Q, British Columbia Ministry of Health) was used to screen participants for cardiac and other health problems, such as dizziness, chest pain, or heart trouble (Hafen and Hoeger 1997). Any participant who answered "yes" to any of the questions on the PAR-Q was excluded from the experiment. The average age, weight, and height of the participants were 20.8 years, 75.6 kg, and 179.4 cm, respectively.

2.2. Equipment

Raw EMG signals were collected using a Tringo wireless EMG system (Delsys Inc., Boston, MA, USA). The surface EMG electrodes were Trigno sensors (Delsys) with a single differential configuration, a parallel bar (99.9% pure silver) contact area, and a fixed inter-electrode distance of 10 mm. They were set at a band-pass filter of 20–450 Hz and a common mode rejection ratio of 80 dB. Two electrodes were attached to the LES, 3 cm lateral to the L3 spinous process (McGill 1991), and TES, 5 cm lateral to the T9 spinous process (McGill 1991). The skin was prepared before attaching the electrodes by shaving the areas over the muscle sites and cleaning them with alcohol. The data was collected at a sampling rate of 2000 Hz and processed using the root mean square method with a time window of 0.125 s and an overlap of 0.0625s (De Luca 1997; Konrad 2005). The EMGworks software (Delsys Inc., Boston, MA, USA) was utilized for processing and analyzing the collected data. Also, straps and an electrically-adjustable therapy table (55 cm x 190 cm) were used to facilitate the performance of the MVC exercises.

2.3. Experimental procedures

Participants were provided with an orientation, which introduced them to the purpose of this research, the equipment, the data collection procedures, and the specifics of the experimental tasks. They began with a warm-up session for three minutes consisting of different stretches for the joints involved. The EMG electrodes were then attached to the muscle sites as described in Section 2.2. Next, they performed five different MVC exercises that were identified in the literature to elicit high EMG amplitudes from the LES and TES. These exercises included the following:

Declined trunk extension (Figure 1a): Participants lied prone on an examination table. The upper body was positioned in a negative 60° angle from the horizontal. The legs and thighs were tightly secured to the table with two straps. Then trunk extension was performed against manual resistance at the shoulders (Plamondon et al. 1999).

- Prone trunk extension (Figure 1b): Participants lied prone on an examination table. Then trunk extension was performed against manual resistance at the shoulders (Vera-Garcia, Moreside, and McGill 2010; McGill 1991).
- Standing trunk extension (Figure 1c): In a standing position facing the wall, participants performed trunk extension against manual resistance at the shoulders (McGill 1991; Jorgensen and Nicolasien 1986).
- Hip extension (Figure 1d): Participants lied prone on an examination table. The legs were extended horizontally off the table's edge. Then hip extension was performed against manual resistance at the knees (Vera-Garcia, Moreside, and McGill 2010; Ng and Richardson 1994).

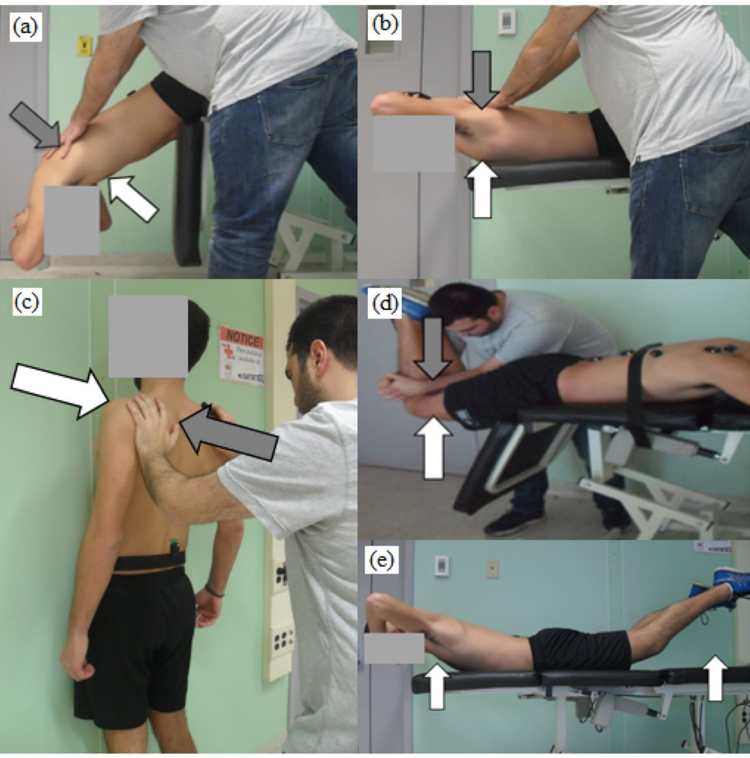

Figure 1. Pictures of the MVC exercises for the LES and TES muscles: (a) declined trunk extension; (b) prone trunk extension; (c) standing trunk extension; (d) hip extension; (e) the arch test; the white arrows represent the forces of the participant, and the gray arrows represent the resistance of the experimenter.

- The arch test (Figure 1e): Participants lied prone and gradually hyperextended their upper trunk and hips upwards. This position was held for 5 seconds (Ng and Richardson 1994).
- Participants were trained on each exercise before data collection to ensure correct performance. Clear instructions were given to them to perform maximum contractions. They were asked to gradually exert up to their maximal force in 3 to 5 s, hold it for 3 s, and gradually decrease the force in 3 s (Konrad 2005). However, EMG data was collected for a slightly longer time period (15 s) to avoid rushing participants and the examiner in performing the MVC exercises. This increased duration did not affect the analysis, since the maximum EMG signals were the only measures of interest. The order of exercise presentation was randomized among the participants. Three repetitions were performed per exercise, and the average of the maximum EMG signals was computed. Repetitions were separated with 30 to 60 s of rest, and the different MVC exercises were separated with 2 minutes of rest (Konrad 2005).

2.4. Experimental design and statistical analysis

A repeated measures, one-way analysis of variance (ANOVA) was used to assess the effects of the MVC exercises on the muscles' maximum activation capacities. The independent

variable in this study was the MVC exercise, which consisted of five levels. The dependent variables were the EMG values of the LES and TES muscles. The experiment consisted of 15 trials, accounting for three repetitions per exercise. Post-hoc multiple comparison analysis was performed using the Bonferroni test to determine the source(s) of the significant effect(s). A significance level (α) of 5% was used to calculate the "Bonferroni adjustment."

3. Results

Figure 2 presents the EMG averages for the different MVC exercises at the LES muscle. The averages for the different exercises were found to be close to each other with the exception of declined trunk extension, which had a relatively lower average. The ANOVA results showed that significant differences existed between the means (p-value < 0.0001). The statistically significant pairwise comparisons between the five MVC exercises are shown in the form of letter groupings in Figure 2. Exercises that did not share at least one letter in common indicated that their means were significantly different. As such, the results show that the declined trunk extension (0.049 ± 0.007 mV) was significantly different from prone trunk extension (0.080 ± 0.011 mV), hip extension (0.089 ± 0.013 mV), and the arch test (0.087 ± 0.010 mV); however, it was not significantly different from standing trunk extension (0.078 ± 0.010 mV). Furthermore, declined trunk extension was the only exercise not to elicit the highest EMG activity in any of the participants (Table 1). On the other hand, the MVC exercise associated with the highest EMG average was hip extension; however, its mean was not significantly different from the means of the arch test, prone trunk extension, and standing trunk extension. Approximately 20% of the participants achieved their highest EMG amplitude using this exercise. The exercise that showed the most consistency (or reliability) in eliciting the highest EMG activity in participants was the arch test; about 40% of the participants achieved their highest EMG amplitude using this exercise. The results showed that there is no one exercise that consistently achieved the highest EMG amplitude in all the participants. Several MVC exercises may have to be performed to achieve the highest EMG activation in an individual.

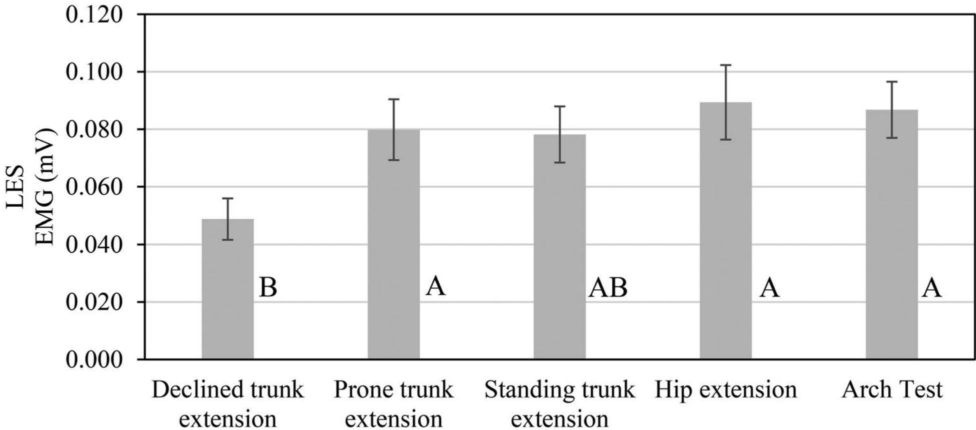

Figure 2. Average EMG amplitudes with standard error bars associated with the different MVC exercises in the LES muscle. Exercises that did not share at least one letter in common indicated that their means were significantly different.

Table 1. The percentage of times each exercise elicited the highest EMG amplitude in the LES and TES muscles among all the participants.

Exercise	LES	TES
Declined trunk extension	0%	0%
Prone trunk extension	6.67%	26.67%
Standing trunk extension	33.33%	13.33%
Hip extension	20.00%	26.67%
Arch test	40.00%	33.33%

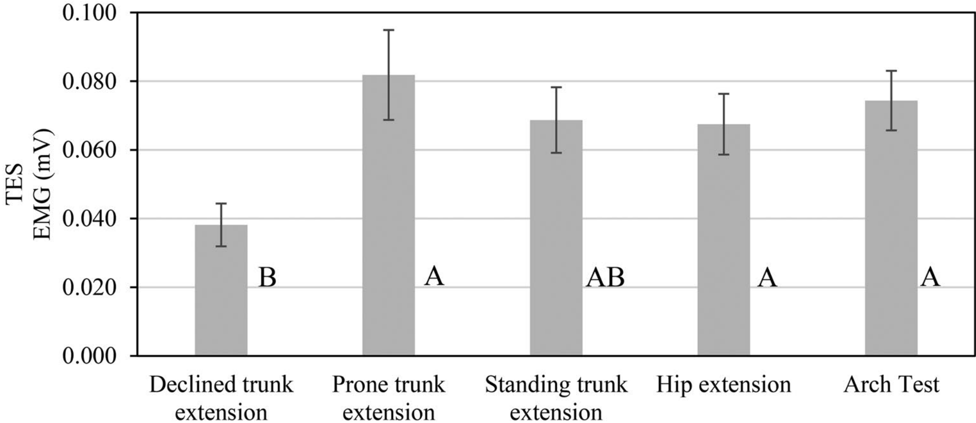

Figure 3. Average EMG amplitudes with standard error bars associated with the different MVC exercises in the TES muscle.

The same MVC exercises were also compared at the TES in their ability to elicit the muscle's maximum EMG amplitude. Figure 3 presents the EMG averages for the different exercises. A similar finding was recognized for this muscle, in that declined trunk extension (0.038 ± 0.006 mV) had the lowest EMG average and none of the participants elicited their highest EMG amplitude using this exercise (Table 1). The ANOVA test showed that significant differences existed between the means (p-value < 0.0001). The Bonferroni results, which were summarized in the form of letter groupings in Figure 3, identified the sources of these significant differences. As in the case of the LES muscle, declined trunk extension was significantly lower than all other exercises, except for standing trunk extension. On the other hand, prone trunk extension (0.082 ± 0.013 mV) reported the highest EMG average; however, its mean was not significantly different from the means of standing trunk extension (0.069 ± 0.010 mV), hip extension (0.068 ± 0.009 mV), and the arch test (0.074 ± 0.009 mV). In terms of consistency in eliciting the highest EMG in participants, prone trunk extension ranked second with a percentage of 26.67% (Table 1). The arch test, again, ranked first for eliciting the highest EMG amplitude in most of the participants with a percentage of 33.33%. However, as in the case of the LES muscle, there is no one exercise that consistently elicited the highest EMG amplitude in all the participants.

4. Discussion

This research compared recommended MVC exercises for two back muscles frequently used in ergonomics research, which were the LES and TES. As of yet, a lack of consensus

exists in the literature regarding the most appropriate MVCs for these muscles. Using an accurate MVC in EMG normalization is essential for understanding a muscle's true effort relative to its maximal activation capacity. Therefore, five recommended exercises across different studies were examined in order to identify the overall most effective exercise in eliciting each muscle's MVC. The present study found that all exercises proved to be effective in eliciting the MVC in at least one participant, except for declined trunk extension; none of the participants achieved their highest EMG amplitude using this exercise. As past research have suggested (Burden 2010; Vera-Garcia, Moreside, and McGill 2010), this study confirmed that there is no one exercise that will consistently achieve the highest EMG amplitude in all participants. Several exercises may need to be performed in order to achieve a person's true MVC. Having said that, some exercises may still be more favorable than others when considering, not only their EMG averages, but also, their variability (e.g. standard error) and consistency in eliciting the highest EMG amplitude among participants. In cases of time limitations, experimenters may be required to use only one MVC exercise for their study. Therefore, the authors highlighted other advantages of the MVC exercises, besides the average EMG amplitudes.

For the LES, the EMG average was greatest during hip extension; however, it was not significantly greater than prone trunk extension, standing trunk extension, and the arch test. Similarly, Vera-Garcia, Moreside, and McGill (2010) reported that, among eleven different MVC exercises, hip extension had the highest EMG average, but it was not significantly greater than prone trunk extension; standing trunk extension and the arch test were not considered in their study. On the contrary, Ng and Richardson (1994) found hip extension to be associated with the lowest EMG average in comparison to exercises similar to prone trunk extension and the arch test. However, a notable difference in their study is that the MVC exercises were not performed against an examiner's manual resistance but rather against gravity. With resistance from an examiner, the resulting EMG activity from hip extension appears to increase. A downside of this exercise is that it was not the most consistent in eliciting the highest EMG amplitude among participants; only 20% of the participants elicited their highest EMG amplitude using this exercise. The arch test was also an effective MVC exercise for the LES, with only a 3% drop from the EMG average of hip extension. Its standard error was relatively low, meaning it produced more consistent EMG amplitudes. Furthermore, most of the participants (40%) elicited their highest EMG amplitude in this exercise. As such, the arch test appears to be slightly more favorable than hip extension, if only one exercise was to be selected. Also, prone and standing trunk extension exercises elicited the highest EMG amplitudes for some of the participants (6.67% and 33.33%, respectively), and their means were not significantly different from the arch test and hip extension. McGill (1991) showed that the MVC of the LES was consistently obtained from prone trunk extension; however, his investigation did not include hip extension and the arch test. All four exercises may need to be performed (arch test, hip extension, prone trunk extension, and standing trunk extension) if the true or most accurate MVC of the LES is desired. The only exercise that proved to be less effective in eliciting the MVC of the participants was declined trunk extension. It was associated with the lowest EMG average, and none of the participants elicited their highest MVC using this exercise.

For the TES, prone trunk extension was associated with the highest EMG average, but it was not significantly different from the means of the arch test, standing trunk extension, and hip extension. Vera-Garcia, Moreside, and McGill (2010) also reported the highest

EMG average at the TES using prone trunk extension, which was not significantly different from hip extension. Although statistical differences were not detected, both the present study and Vera-Garcia, Moreside, and McGill (2010) recognized higher EMG averages using prone trunk extension in comparison to other exercises. McGill (1991) and Vera-Garcia, Moreside, and McGill (2010) found that prone trunk extension was the most frequent exercise to elicit the highest MVC in the TES. On the other hand, the present study found the arch test to be even more consistent than prone trunk extension in eliciting the highest EMG in participants (33.33% and 26.67%, respectively). The arch test was not examined in neither Vera-Garcia, Moreside, and McGill (2010) nor McGill's (1991) studies. Also, of the four exercises that were not significantly different from each other, the arch test was associated with the lowest standard error. Furthermore, it had the second largest EMG average, which was not significantly different from prone trunk extension. As such, the arch test appeared to be the overall most effective MVC exercise also for the TES. However, to guarantee the true MVC, several exercises may need to be performed, including prone trunk extension, arch test, standing trunk extension, and hip extension. Declined trunk extension, again, was the only exercise not to elicit the highest EMG amplitude in any of the participants.

This research consisted of a few limitations that may be explored further in future research. First, the findings of this study are limited to surface electrode EMG and to the electrode sites used. Generalizing the findings herein to needle electrode EMG may be inaccurate. Second, the low number of participants could have affected the ability to detect significant differences between MVC exercises. A future study may consider recruiting more participants to confirm the findings of the present study or possibly detect more significant differences between exercises. Third, this research did not consider MVC exercises other than those presented in the literature. There may be exercises that have not yet been developed that are even more effective in eliciting the MVC of the LES and TES. Al-Qaisi and Aghazadeh (2015) proposed new MVC exercises, however, for two shoulder muscles, which they proved to be more effective than conventional MVC exercises in the literature. Similarly, in the case of the LES and TES muscles, there may be exercises – such as simultaneous extension and twisting of the trunk or hips – that are even more effective than those presented in the literature. Lastly, the method followed in this study for generating MVCs was designed for individuals with no musculoskeletal pain. If an individual has a pre-existing musculoskeletal pain, the examiner may need to adjust this method, in order to avoid fatigue or injuries. For example, instead of 9 or 11 s of contraction time and 30 or 60 s of rest between trials (Konrad 2005), the examiner can reduce the contraction time to 3 s (Soderberg and Knutson 2000) with 3 min rest between trials (Dankaerts et al. 2004; McLean et al. 2003). Alternatively, the examiner may rely on sub-maximal voluntary contractions (sub-MVC), which have been reported to be more reliable than MVCs in a pain population (McGill 1991; O'Sullivan et al. 2002) and more sensitive to low levels of muscle activation (Allison, Godfrey, and Robinson 1998; O'Sullivan et al. 2002; Snijders et al. 1995).

5. Conclusions

This research comparatively investigated different MVC exercises that were recommended in the literature for the LES and TES muscles; these two muscles were specifically

considered for being among the most frequently investigated back muscles in the ergonomics literature. Findings showed that none of the five exercises consistently elicited the highest EMG amplitude in all the participants. Rather, all exercises, with the exception of declined trunk extension, elicited the highest EMG activity in at least one participant. Therefore, several exercises may have to be performed in order to determine the true or most accurate MVC of a person. If time is limited and the experimenter is restricted to using only one exercise, the authors recommend the arch test, which: had a high EMG average; was the most consistent to elicit the highest EMG amplitude in the participants; and had relatively low variability. Other advantages of this exercise was that it proved to be more favorable for both the LES and TES muscles; so by performing only one exercise, the MVC may be achieved for both muscles. Also, the arch test was the only exercise that did not require manual resistance from the experimenter; rather, this exercise was performed only against gravity. If the true or most accurate MVC is desired, the authors additionally recommend performing hip extension, prone trunk extension, and standing trunk extension for both the LES and TES muscles. The means of these exercises were not significantly different from each other, and also, they all achieved the highest EMG amplitude in at least one participant.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Notes on contributors

Dr. Saif Al-Qaisi is an Assistant Professor in the Industrial Engineering and Management Department at the American University of Beirut (AUB). He completed his Bachelor of Science Degree in Industrial Engineering from Louisiana Tech University. Then he moved to Louisiana State University to complete his graduate studies, earning a Master of Science Degree in Industrial Engineering, a Master-Minor in Applied Statistics, and a Doctorate Degree in Engineering Science, with a focus in Human Factors and Ergonomics. Upon joining AUB as an Assistant Professor, he established the Human Factors and Ergonomics Lab, which is used both for research and teaching purposes. His research revolves around physical ergonomics, work-related musculoskeletal disorders, and ergonomics in healthcare. More specifically, he has focused in the development of ergonomic handwheel-valve designs and standards based on operators' physical capacities and biomechanics. Also, he has conducted research in healthcare to reduce physical loads acting on healthcare providers, including nurses when performing patient-handling tasks and surgeons in the operating room. He has authored over 23 publications in these fields in refereed journal articles and international conferences.

Alif Saba completed his Civil Engineering Degree from the University of Aleppo. Then he joined the American University of Beirut to complete a Master in Engineering Management, with a focus in Human Factors and Ergonomics.

Dr. Ibrahim Alameddine received both his BS in Biology and MS in Environmental Technology from the American University of Beirut (AUB) and his PhD in Environmental Sciences from Duke University. He is currently an Assistant Professor at the Civil and Environmental Engineering Department at AUB. His research interests primarily focus on the development of probabilistic models that better our understanding and management of complex environmental systems while accounting for uncertainties. He is particularly interested in the monitoring, modeling, and management of nutrient loading, eutrophication, and harmful algal blooms. His work also explores the potential to harness remote sensing and low cost monitoring platforms towards improving our understanding of poorly monitored environmental systems. Prior to joining AUB, Dr. Alameddine was a Postdoctoral Fellow at the University of Michigan- Ann Arbor and previously worked as an environmental consultant on several projects that were funded by international organizations and governmental entities in the fields of environmental and water resources management as well as environmental monitoring and modeling. Dr. Alameddine has more than 50 peer-reviewed manuscripts, proceedings, and professional reports in various prestigious international and regional outlets. He was also the recipient of the Anchor QEA L.L.C. scholarship for young scientists.

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