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Reliability of normalisation methods for EMG analysis of neck muscles

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Abstract. Acceptable reliability of normalisation contractions in electromyography (EMG) is paramount for testing conducted over a number of days or if normal laboratory strength testing equipment is unavailable. This study examined the reliability of maximal voluntary isometric contractions (MVIC) and sub-maximal (60%) isometric contractions for use in neck muscle EMG studies. Surface EMG was recorded bilaterally from eight sites around the neck at C4/5 level from five healthy male subjects. Subjects performed MVIC and sub-maximal normalisation contractions using an isokinetic dynamometer (ID) and a portable cable dynamometer with attached strain gauge (PCD) in addition to a MVIC against a manual resistance (MR). Subjects were tested in flexion, extension, left and right lateral bending and were retested by the same tester within a two-week period. Intra class correlation co-efficients (ICC) were calculated for each testing method and contraction direction and a mean ICC was calculated across all contraction directions. All normalisation methods produced excellent within-day reliability (mean ICC $>$ 0.80) but only the MVICs using the ID and PCD had acceptable reliability when assessed between-days. This study confirmed the validity of using MVICs elicited using the ID and PCD as reliable reference contractions for the normalisation of neck EMG.

Keywords: Electromyography, neck, cervical, reliability, normalisation

1. Introduction

Processing of electromyographic (EMG) signals via normalisation to a reference contraction is essential if the resulting signals are to be compared between conditions and/or subjects [11]. In previous EMG studies examining individual muscles of the neck, raw EMG signals have been predominantly normalised to a maximal voluntary isometric contraction (MVIC) [3,10, 18]. As these studies have focused upon various light occupational tasks such as work at video display terminals, sewing machine operation and dental work, the resulting amplitude of the EMG signal has been small. Therefore, the MVIC method of normalisation produces activation levels below 100% during these tasks [18]. Alternatively, EMG has been used to investigate muscle strain the neck is placed under in high performance combat pilots (HPCP) undertaking aerial combat manoeuvres [16]. Reports of muscle activation above 100% MVIC have not been uncommon and they have been attributed to the high gravitational forces experienced during flight [7].

There have been various methods used to elicit an MVIC from the muscles of the neck. In the laboratory environment, dynamometry set-ups have been used [10, 14] however, in field-based applications, the methods to elicit an MVIC have tended to be much less complex and subsequently more portable. For example, a leather cuff fitted securely around the forehead, linked to a chain fastened to a wall has previously been used to elicit an MVIC [15,16,19]. To date, there have been no studies that have specifically examined the reliability of these normalisation methods with reference to the neck musculature [18]. Furthermore, it has previously

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been found in muscles other than those of the neck, that sub-maximal normalisation contractions are more reliable than the process of MVIC normalisation [1, 20]. Therefore, there exists a rationale for examining sub-maximal normalisation methods for the muscles of the neck.

There is a paucity of reliability data for EMG analysis of the neck muscles available in the literature. Researchers who collect EMG from the neck muscles tend to use MVIC to normalise their data [18]. The purpose of this study was to determine the best method of obtaining a reliable reference EMG signal that could be used for normalisation of EMG data collected from the neck. The normalisation process should allow the resulting signal to be utilised as an investigation tool to reliably quantify muscle activation levels between 0 and 100% in most tasks.

2. Methods

2.1. Subjects

Five healthy male subjects (28.6 $\pm$ 5.8 yrs) participated in the study. All subjects selected for the study met the inclusion criteria outlined by Sommerich et al. [18] for neck EMG measurement. All experimental procedures were approved by the Edith Cowan University's Human Ethics Committee and informed consent was obtained from each subject prior to the commencement of testing.

2.2. Electrode placement

EMG activity was recorded bilaterally from four sites around the neck at the C4/C5 level [3,14]. An outline of the electrode placements, intended muscle coverage and exact locations is given in Table 1.

Pairs of 12 mm diameter Ag-AgCl disposable surface electrodes (Uni-Patch, Wasbasha, MN, USA) were placed 20 mm centre-to-centre distance apart at each of the above mentioned sites after the subject's skin had been thoroughly prepared by shaving, lightly abrading and cleaning with alcohol [6,9]. Separate ground placements were used for each channel. Raw EMG signals were collected via an eight channel ME3000 portable data logger (Mega Electronics, Kuopio, Finland) with miniature analogue differential amplifiers (bandwidth: 8–500 Hz, common mode rejection ratio: 110 dB, gain: 375). Signals were digitally recorded by the data logger onto a 32 MB flash memory PCMCIA standard card. EMG signals were sampled at 1000 Hz.

2.3. Experimental protocol

Three different testing methods were examined in this study. Subjects performed both maximal (100%) and sub-maximal (60%) isometric contractions using an isokinetic dynamometer (ID) and a portable cable dynamometer with an attached strain gauge (PCD). Furthermore, a maximal isometric contraction was generated by applying a manual resistance (MR) to the head.

To ensure that each subject's neck was isolated, all subjects were tested in a seated position and each subject's torso and shoulders were restrained to a flat-backed weight-lifting bench angled to 90°, using tightly fitted straps. In each of the five testing methods, four main movements were tested to elicit isometric contractions for each of the electrode sites used. The isometric contractions tested were flexion (Flex), extension (Ext), left lateral bend (LLB) and right lateral bend (RLB). All efforts were made to ensure subjects performed these contractions in the specific planes and that extraneous non-planar movements were minimised. These included aligning the resistance orthogonal to the intended movement, the use of a curved pad that moulded to the subject's head in ID and the use of a non-slip head cuff in PCD. Contraction directions and testing methods were randomised to avoid attaining any ordering effect. Subjects were retested by the same tester within two weeks of the initial test, and testing took approximately one month to complete.

Tests using the ID (Cybex 6000, Rononkoma, NY) consisted of three, five-second MVICs followed by two, five-second 60%-MVICs in a seated position against a torque arm (Fig. 1). The axis of rotation of the torque arm was aligned at each subject's C4/5 level. A two-minute rest period was allowed after each exertion to allow full recovery. Torque histories for each contraction were recorded from the ID at 200 Hz using Amlab V2® software (Lesingham, Aust.) and these were later used to ascertain the 60%-MVIC level. EMG was only recorded from the last two contractions for the maximal condition as recommended by Sommerich et al. [18].

As the subjects' vision was obstructed by the torque arm during the flexion trials, no visual feedback using the computer interface was given during all trials. This was adopted for consistency of results. In its place, concise verbal instructions were given to each subject to increase force until the pre-determined sub-maximal torque value was reached and then subjects were asked to hold the level of contraction.

Table 1
Outline of electrode placements, intended muscle coverage and anatomical locations

Electrode Placement	Vertical Orientation	Intended Muscle Coverage	Anatomical Location
Anterior	Orthogonal to C4/5 ring	Infrahyoid and Platysma	Approx. midway between anterior midline and anterior border of sternocleidomastoid.
Anterolateral	In line with muscle fibres	Sternocleidomastoid	Approx. midway between anterior border and posterior border of sternocleidomastoid.
Posterolateral	In line with muscle fibres	Levator Scapulae	Approx. midway between posterior border of sternocleidomastoid and anterior border of upper trapezius.
Posterior	In line with muscle fibres	Trapezius	Approx. midway between anterior border of upper trapezius and posterior midline.

Fig. 1. Subject performing an MVIC for flexion on the isokinetic dynamometer (ID).

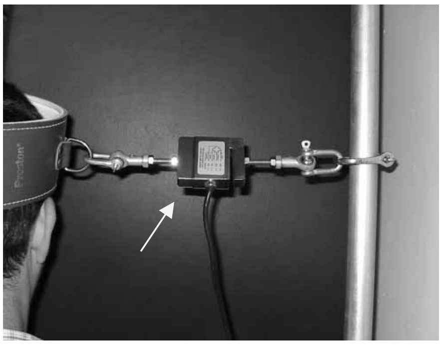

Fig. 2. Subject performing an MVIC for lateral bending using the PCD. Arrow points to the strain gauge which is connected to a digital readout (not pictured).

The PCD consisted of a leather head cuff taken from a cable dynamometer (Lafayette Instruments Co., Lafayette, IN) attached to a 50 kgf strain gauge (Bongsing Co., Korea) via an inextensible wire cable. The strain gauge was connected to a digital display unit (Red Lion Controls, UK) that updated peak strain readings every second. This configuration was attached to a wall-mounted steel rod to allow for variation in subject height. The experimental setup for this testing method is shown in Fig. 2. The contraction regimen was similar to that performed with the ID with the sequence of contractions being randomised. EMG and peak strain readings were recorded for the last two contractions only and subjects were not permitted any visual feedback.

Subjects also performed three, five-second MVICs in each of the four directions against a maximally applied manual resistance. The resistance was placed directly opposing the contraction direction. For example, in the flexion direction, the resistance was placed in the middle of the subject's forehead. A rest period of two-minutes was allowed between each contraction. EMG was recorded from the last two contractions only. Submaximal contractions were not examined due to the difficulty of estimating a 60% contraction.

2.4. Data reduction and statistical analysis

Raw EMG signals were downloaded from the memory card in ASCII format via an optical interface and serial accelerator port (Digi International, Minnetonka, MN, USA) onto a laptop computer. The resulting files were then manipulated in a customised LabView V6.1® (National Instruments, Austin, TX, USA) software program where EMG signals were full wave rectified and low-pass filtered at 5 Hz using a fourth-order, dual pass Butterworth digital filter. The maximum activation for each channel was calculated by taking the average over a 200-msec window [13]. Only activations collected from the agonistic muscles for each contraction were used for comparisons. For example, in the flexion direction, only activations collected from the anterior and anterolateral placements were used. As EMG was sampled bilaterally, activations from the left and right lateral bend were averaged to obtain a composite lateral bending reading.

Maximum activations between each trial were compared for each test method and the mean values of the two trials were calculated. These values were used for comparison between days for each test method. Three indices of reliability were then calculated they being; the intra class correlation co-efficient (ICC), the absolute Standard Error of Measurement (SEM) and the relative SEM (%SEM) [4]. The ICC was obtained using SPSS V10.0 and these values were tabulated in a Microsoft Excel spreadsheet where the SEM was calculated as follows:

$$SEM = S_X\sqrt{1 - ICC}$$

Where, S_X was the pooled standard deviation. The %SEM was then calculated by the following:

$$\%SEM = \frac{SEM}{\overline{X}_1 + \overline{X}_2} * 100$$

Where $\overline{X}_1$ and $\overline{X}_2$ were means of each sample. ICC above 0.80 were regarded as excellent reliability.

Torque data from the ID was processed in the Amlab V2® software (Lesingham, Aust.). The plateau section of each contraction was identified visually and exported to a Microsoft Excel spreadsheet. Linear regression was used to calculate the sum of squares (SS) for all torque histories from the ID. These values were used to ascertain the variability of each torque reading.

3. Results

Mean ICC readings across all contraction directions showed excellent within-day reliability for all testing methods. MVIC elicited in the ID and via MR proved most reliable (mean ICC = 0.92 and 0.96, respectively). MVIC elicited with the PCD and the sub-maximal normalisation contractions were marginally less reliable. (PCD ICC = 0.90, ID 60% ICC = 0.86, PCD 60% ICC = 0.84). Mean %SEM were deemed acceptable across all methods (%SEM = 2.3%–7.1%). Table 2 details the results for each testing method and contraction direction.

MVICs elicited using the ID and PCD showed excellent reliability between-days (mean ICC = 0.89). MVIC elicited via MR showed a slightly decreased reliability (MR ICC = 0.83, %SEM = 10.1%) in comparison. The sub-maximal normalisation methods yielded much lower reliability when all contraction directions were considered (ID 60% ICC = 0.55, %SEM = 20.7%; PCD 60% = 0.64, %SEM = 18.1%) and these results were deemed to be unacceptable. Figure 3(a) and (b) display the mean ICCs and %SEMs across all contraction directions for within-day and between-days comparisons.

4. Discussion

4.1. Limitations of the study

The major limitation of this study is the restricted sample size. The results can only be extrapolated to healthy adult males, aged 23 to 35 years.

4.2. Maximum voluntary isometric contractions

Excellent within-day reliability was obtained for all MVIC testing methods. These results were expected as the peak torque readings from the ID and PCD were relatively constant between trials. It was interesting to note that all torque readings from the first contraction for each contraction direction (where EMG was not collected) showed a ramped but non-maximal effort. This supports the recommendations of Jensen et al. [8] that more than one maximal contraction should be used when estimating maximal activations and Sommerich et al. [18] suggested not using the first maximal contraction as it may not depict a true maximum.

MVICs with the ID and PCD showed excellent reliability between-days. Efforts in MR however were slightly less reliable. These results suggest an exclusion of systematic errors in electrode placement can be made therefore, a closer examination of the ICC from each contraction direction was necessary. ICCs for ID and PCD were less variable in each contraction direction when compared to those obtain by MR (Table 2). This may be due to inconsistency in the point of application of the applied resistance. Slippage between the applied resistance and the subject's head may have also exacerbated the problem. This could explain the much higher ICC obtained in extension when compared to flexion and lateral bending, as the ability to maintain the subject's head in a stable posture without slipping was much easier in the extension trials when compared to flexion and lateral bending. Although convenient in its application, MVICs collected from MR for field-based studies cannot be considered reliable as the subject's head tended to move slightly in relation to the applied resistance during testing. These results are in agreement with Sommerich et al. [18] who recommend not using this method of eliciting MVIC as true isometric contractions could not be guaranteed.

Averages activation levels when all contraction directions were 9.3% higher in the PCD and 1.2% higher in ID than those produced using MR. This may be of value if large activation levels are being measured, such as those recorded from HPCP during aerial com-

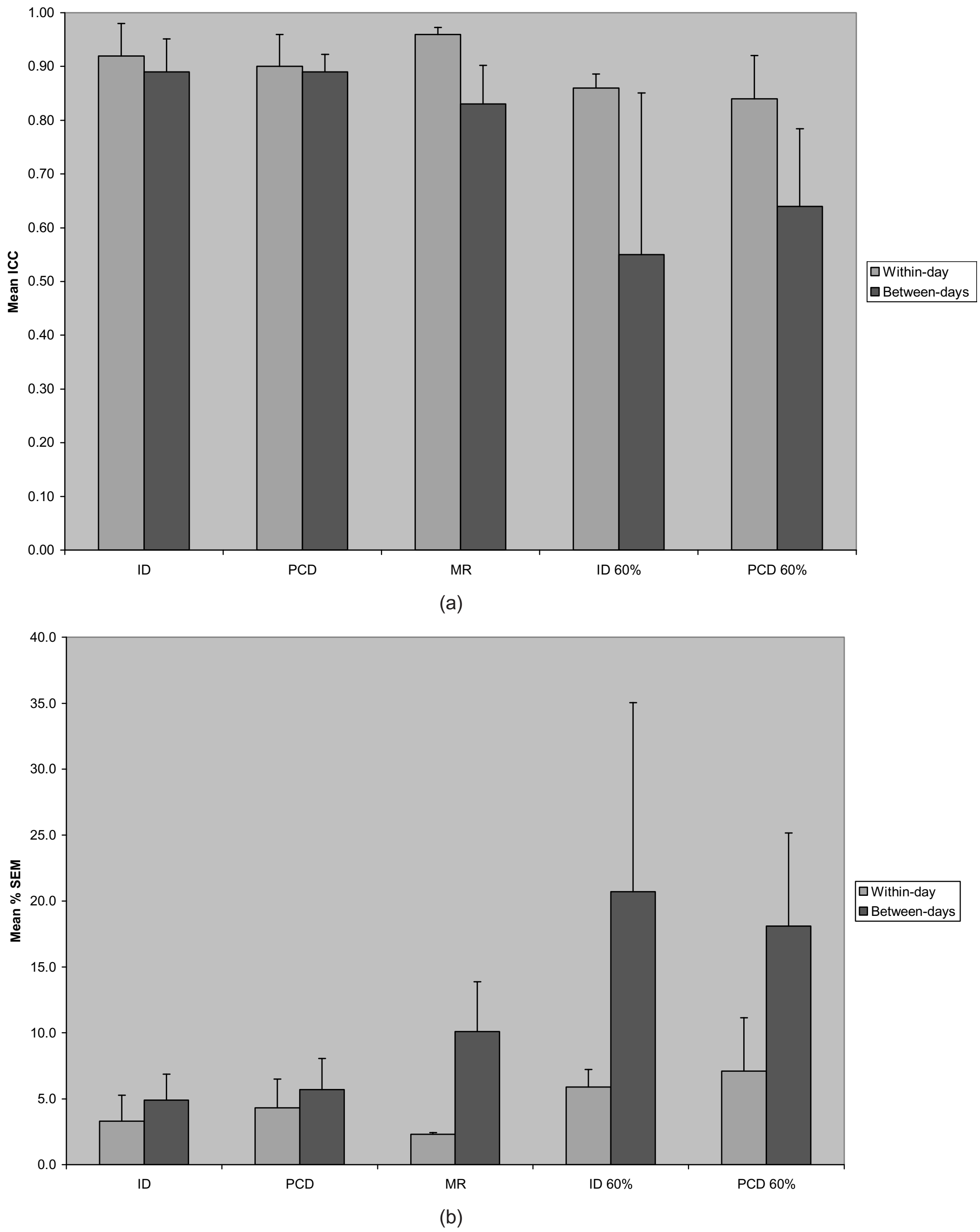

Fig. 3. (a) Mean within-day and between-days ICC values across all contractions for each normalisation method. (b) Mean within-day and between-days %SEM values across all contractions for each normalisation method.

bat manoeuvering. Oksa et al. [16] reported peak EMG readings of 257% of MVIC when EMG from the lateral neck was measured during aerial combat manoeuvring. In their study, the normalisation contraction was elicited by restraining the head whilst lying supine and it is questionable whether a true MVIC was generated from this method. MVICs from the ID and PCD as performed in this study could be better used as a reference to large activation levels from in-flight recordings.

4.3. Sub-maximal voluntary isometric contractions

Previous studies have suggested sub-maximal contractions are more reliable than maximal contraction in

Table 2
Within-day and between-days ICC and %SEM for all contraction direction

	Extension		Flexion		Lateral Bending	
	ICC	%SEM	ICC	%SEM	ICC	%SEM
Within-day						
ID	0.95	1.7	0.85	5.5	0.95	2.8
PCD	0.84	6.8	0.89	3.6	0.96	2.6
MR	0.95	2.4	0.95	2.4	0.97	2.2
ID 60%	0.83	6.5	0.89	4.4	0.86	6.9
PCD 60%	0.78	8.0	0.93	2.7	0.80	10.7
Between-days						
ID	0.82	7.1	0.91	3.9	0.93	3.6
PCD	0.85	8.4	0.90	4.1	0.91	4.7
MR	0.91	6.1	0.78	10.8	0.80	13.5
ID 60%	0.89	4.5	0.32	31.6	0.43	26.1
PCD 60%	0.72	16.3	0.47	25.9	0.72	12.1

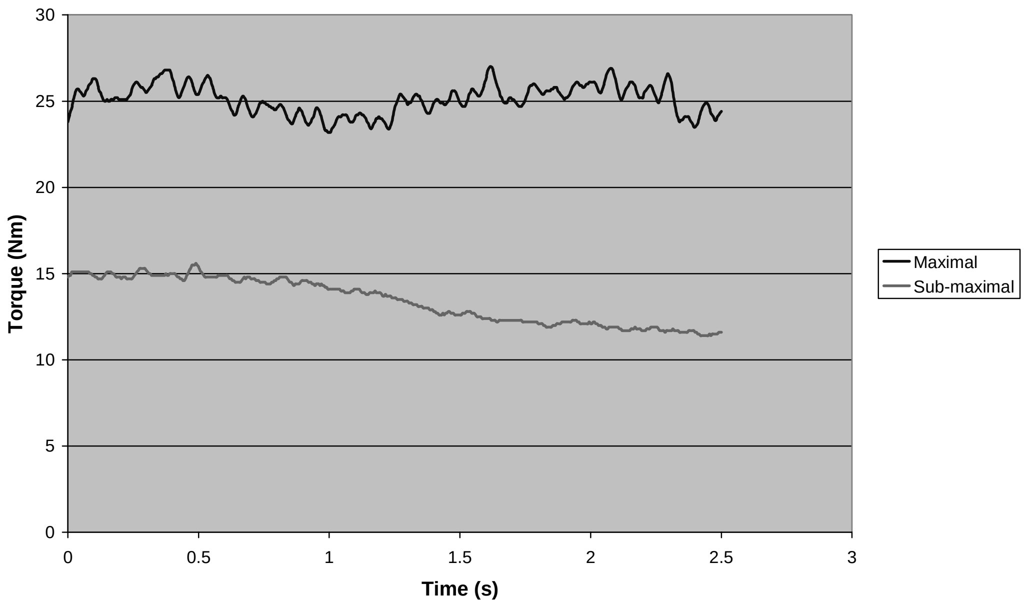

Fig. 4. Raw torque histories from the ID illustrating an MVIC and a sub-maximal normalisation contraction in extension. The ramped portion of the contraction prior to the attainment of the required torque has been excluded.

various muscles of the body [1,20]. In this study, both sub-maximal normalisation methods proved to be very reliable within-day but produced much poorer results between-days. The difference in the body part examined in previous studies may explain the contrary findings. Yang and Winter's [20] investigation examined a singular muscle (tricep) spanning a uniaxial joint and this has very little correlation to sub-maximal contractions in the neck, which may be more reliant on synergistic and stabilising muscles as opposed to prime movers in sub-maximal contractions [5]. The complexity of the neck's musculature and its triaxial movement may further explain the contrary findings.

Falla et al. [5] examined the repeatability of a number of EMG-related variables in the sternocleidomastoid and anterior scalene muscles while performing sub-maximal (50%) isometric contractions in flexion. While their study did not contrast the reliability of MVIC to sub-maximal contractions, they reported good within-day (%SEM = 5.43%) and between-days (%SEM = 23.90%) reliability when the average rectified value of the signal from the sternocleidomastoid muscle was compared. These findings are similar to the results obtained in this study when the results from the anterior and anteriolateral EMG placements for sub-maximal flexions were considered within-day and between-days.

Torque histories, collected from the ID, showed MVICs as being less variable (average SS $= 0.14$) when compared to sub-maximal efforts (average SS $= 0.37$). The increase in variability of torque in the sub-maximal efforts may explain the decrease in EMG reliability between-days. During testing, subjects commented on the difficulty of maintaining a sub-maximal contraction. This was evident when the slopes of the regression lines were compared. A negative slope in the torque-time graphs, indicating a decrease in torque production, was common to many sub-maximal efforts (the average gradient was -0.51 for all sub-maximal efforts). An illustration of a typical maximal trial compared to a sub-maximal trial is given in Fig. 4. This figure clearly shows a decrease in torque once the required level was attained. Future investigations may include visual feedback during sub-maximal normalisation contractions to better allow subjects' to maintain a required torque.

Queisser et al. [17] reported electrocardiographic (ECG) artefact in a number of EMG readings sampled from various neck extensor muscles and Mekhora and Straker [12] suggested ECG may contaminate EMG data during low level static tasks if the EMG is sampled from muscles near the heart. In our study, ECG was detected in the anterior and anteriolateral electrode placements in many subjects during the rest phase prior to beginning the next contraction in the experimental protocol. The contaminant was undetectable during MVICs where the activation levels were much higher than the peak ECG amplitude. ECG contamination may be more influential in the sub-maximal contractions, where activation levels were lower. This may help to explain the inconsistencies in reliability across the various contraction directions in the sub-maximal efforts. The reliability in extension contractions between-days for both MVIC and sub-maximal contractions were higher when compared to lateral bending and flexion (Table 2), which both exhibited ECG contamination during rest periods prior to efforts. Bauer and Wittig [2] suggested high-pass filtering at 40 Hz to eliminate ECG, whereas Mekhora and Straker [12] suggested a more elaborate scheme of collecting both ECG and EMG synchronously and using certain points in the ECG as a gate to eliminate the noise in the EMG data. Sommerich et al. [18] proposed a similar system of only considering EMG signals between heartbeats. The abovementioned schemes have merit but need to be tested with consideration to the activity being investigated.

5. Conclusions

This study shows a reliable reference EMG signal can be obtained from the neck muscles for the purpose of normalisation for both the MVICs from the ID and PCD. Furthermore, MVICs elicited from these devices proved to be more reproducible when compared to sub-maximal normalisation methods. The use of the PCD can be advantageous if EMG studies of the neck muscles need to be conducted in the field where normal laboratory based equipment is unavailable. Random ECG contamination and the inability of subjects to maintain a constant sub-maximal effort may have affected sub-maximal reliability.

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