METHODOLOGICAL CONSIDERATIONS FOR COMPARISONS OF UPPER EXTREMITY EMG BETWEEN INDIVIDUALS WITH AND WITHOUT PARAPLEGIA

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This study compared normalization methods for surface electromyography (sEMG) for comparing individuals with (Para) and without (AB) paraplegia. Participants (Para, n=7, AB, n=11) performed 4 minutes of arm-cycling at several submaximal intensities, and an incremental maximal test to exhaustion, while sEMG of the right biceps brachii was recorded. This study analyzed sEMG at two intensities: rate of perceived exertion (RPE) 13 and at 60 W, with four methods of normalization: non-normalized, against a maximal voluntary contraction (MVIC), against a rate of perceived exertion (RPE) 9, and against the max test. Using submaximal exercise intensity based on RPE or power output will affect the results when comparing sEMG of Para and AB groups, regardless of which normalization method is used to inspect the data.

KEYWORDS: arm-cycling, surface electromyography, disability, normalization, MVIC.

INTRODUCTION: Surface electromyography (sEMG) has been used to examine the electrical activity of muscles during a range of activities (Chuang & Acker, 2019). To account for inherent technical differences between independent measurements, including differences in muscle volume between participants and inconsistent electrode placement between testing occasions, normalization of the raw signal is required (Burden, 2010; Lehman & McGill, 1999). While the maximal voluntary isometric contraction (MVIC) is the method most frequently used (Burden, 2010), it has been shown to misrepresent the true maximal excitation capacity of the muscle during dynamic activities (Ball & Scurr, 2013; Sinclair et al., 2015). Instead, researchers have suggested using dynamic activities for normalizing sEMG signals (Albertus-Kajee et al., 2010; Albertus-Kajee et al., 2011; Chuang & Acker, 2019). Research has shown that using dynamic normalization methods yields higher repeatability, better intra-subject reliability and increases sensitivity compared to normalization against an MVIC (Albertus-Kajee et al., 2010; Albertus-Kajee et al., 2011). Dynamic tasks have included normalization against a maximal effort task, such as sprint running (Chuang & Acker, 2019), or a low intensity activity, such as walking (Cronin et al., 2015), and are expected to better represent excitation capacity across groups.
To examine how disability affects sports performance in individuals with paraplegia (Para), it is common to compare their biomechanical parameters, including sEMG, to those of able-bodied (AB) counterparts (Dubowsky et al., 2009; Runciman et al., 2015). For example, Dubowsky et al. (2009) showed that Para used higher %MVIC for the upper arm muscles during wheelchair propulsion at a self-selected speed. The authors suggested that this was due to the compromised function of trunk muscles in the individuals with paraplegia. However, researchers have cautioned that the use of MVIC within clinical populations may be inaccurate since they may be unable to produce maximal contractions (Sinclair et al., 2015), and it remains unclear if the normalization method used to compare sEMG between Para and AB affects the outcome of studies.
It was therefore the aim of this study to compare different normalization methods of sEMG signals of the biceps brachii in individuals with and without paraplegia during arm-cycling.

METHODS: Seven upper-body trained individuals with Para (6 men, 1 woman, age: 33.8±11.2 yrs., height: 1.79±0.11 m, body mass: 74.4±12.5 kg, injury level: T3-L1), and eleven AB cross-country skiers (9 men, 2 women age: 22.4±2.6 yrs., height: 1.83±0.03 m, body mass: 78.1±6.2 kg) participated in the study. All participants provided written informed consent prior to data

collection in accordance the ethics approval (NCT03284086). Participants were fitted with a sEMG sensor (Telemyo 2400T, Noraxon USA inc., Scottsdale, AZ) recording at 1500 Hz on their right biceps brachii, and performed a MVIC according to SENIAM recommendations (Hermens et al., 1999). Following a 5-minute warm-up of arm-cycling at a self-selected speed (at RPE 8-9 on a 6-20 Borg scale (Borg, 1982)), participants performed 3 bouts of 4 minutes submaximal steady state arm-cycling on a custom-made ergometer (White, XXL Sport & Villmark AS, Norway) at the same RPE (9, 11 and 13) and at similar cadence (Para: 78±5, AB: 76±9 rpm). Power output (PO) at a given RPE was lower in Para than AB, so the sEMG was therefore interpolated at 60 W based on the individual PO-sEMG relationship to present the data at the same external workload in addition to at the same RPE. Following the three submaximal bouts, participants were allowed 10 minutes of rest, followed by an incremental test to exhaustion, where the power output was increased by 10 W every minute until exhaustion. sEMG data were obtained for 30s for each of the submaximal stages and in the middle of each stage during the maximal test.
The sEMG data from the MVIC trial, the submaximal stages, and the incremental maximal test was extracted and analyzed in MATLAB version 2020b (MathWorks Inc., Natick, USA) using custom code. The sEMG signals were band-pass filtered (20-400 Hz, 4^{th} order Butterworth), fully rectified, detrended, and lowpass filtered (12 Hz, 4^{th} order Butterworth). Cycles were identified based on a reflective marker placed on the handle of the ergometer, which was tracked by 8 Oqus cameras (Qualisys AB, Gothenburg, Sweden) at 100Hz. Due to the different PO at the given RPE between the groups, we analyzed the sEMG signals at two intensities: RPE 13 and at 60 W, normalized with four different methods: non-normalized, against MVIC, against RPE 9 (low intensity), and against the maximal value achieved during the incremental test to exhaustion (Max). The normalization value for the dynamic tasks (RPE 9 and Max) was the peak value recorded over the corresponding stage. The sEMG signals were time normalized to 100% of a cycle. Independent samples t-tests were used to test for differences between the groups in the peak sEMG data (R Core Team, 2019). Due to the large within-group variation in the sEMG signals for both groups, statistical significance was not reached for most of the comparisons. Therefore, effect sizes were calculated using Cohen’s D and large effect sizes (d>0.8) were considered to indicate a between-group difference in addition to the p-values.

RESULTS:

The analysis showed that the method used for normalization of the sEMG signals affected the maximal amplitude of both the original (RPE-based) and interpolated (60W) signal. Figure. 1 shows the time-normalized EMG traces that the means values in table 1 are based on.

Table 1: Peak sEMG, mean (SD), for the biceps brachii for each of the normalization methods.

	RPE 13				60W			
	Able bodied	Para	P-value	d	Able bodied	Para	P-value	d
Non-normalized (µV)	241 (232)	180 (108)	0.521	0.34	201 (145)	196 (73)	0.933	0.04
MVIC (%)	37 (29)	69 (71)	0.191	-0.60	32 (20)	72 (52)	0.036	-1.00
Max (%)	16 (12)	21 (14)	0.419	-0.39	15 (8)	23 (9)	0.116	-0.79
RPE9 (%)	93 (54)	102 (48)	0.737	-0.17	80 (27)	92 (44)	0.471	-0.34

* d indicates effect size calculated using Cohens’ D

The amplitudes of the collected MVIC were not statistically different between the groups (AB: 620±214µV, Para: 452±392µV, p=0.327, d=0.53). When the intensity was based on RPE13 (PO: Para: 63±16W, AB: 76±11W, p= 0.033, d=0.88), the non-normalized data showed higher levels of excitation within the AB participants, and when the data were normalized against MVIC, the relationship was reversed. (Figure 1). Normalization against the dynamic methods (RPE9 and Max) resulted in similar amplitudes between the groups.
The 60W power output occurred at different RPE for the two groups (Para:12±2, AB: 11±2, p=0.095, d=-0.83). While the non-normalized method had similar amplitudes between the

groups, the amplitude was higher for the Para group compared to the AB with all three normalization methods (Figure 1).

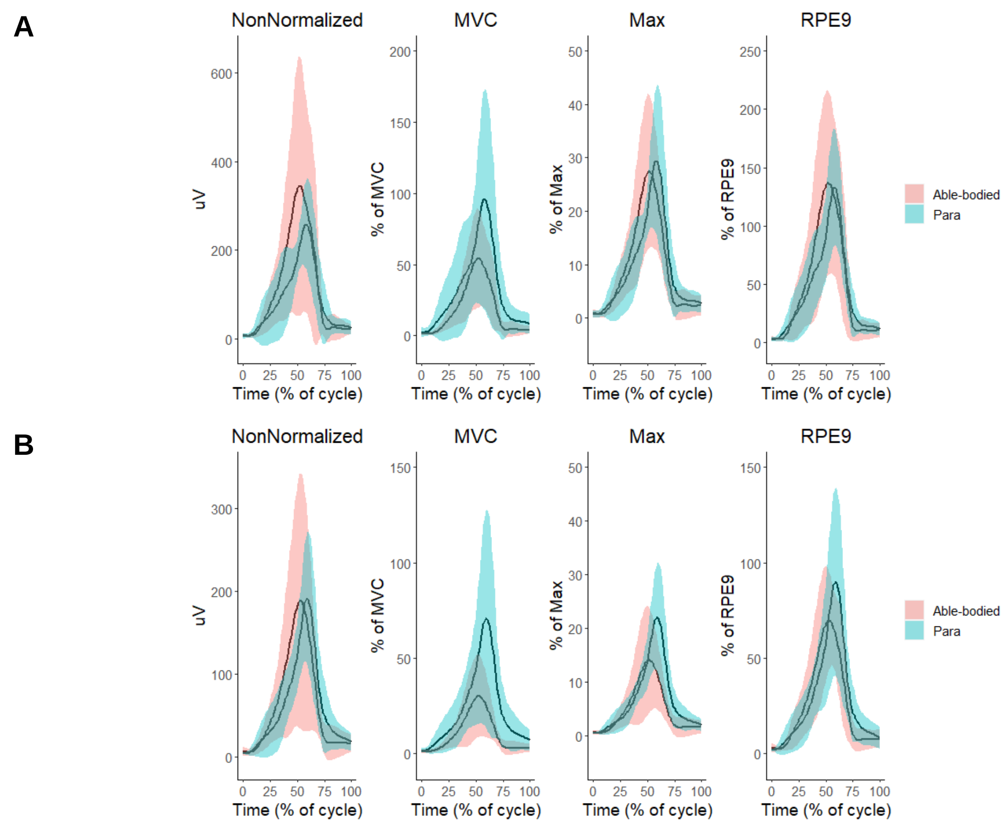

Figure 1: Time series EMG data for the Biceps during 30s submaximal arm cycling at (A) RPE 13 and (B) at power output 60W normalized with 4 different methods.

DISCUSSION:

This study highlights the importance of carefully selecting the normalization method when comparing sEMG signals between AB and Para groups. The different methods affected the amplitudes of both groups and the difference between them.

The non-normalized data suggested that the AB group produced higher muscle excitation levels during the RPE13, while it was similar between group at 60W. When normalization of the data was done against the static MVIC trial, it appeared that the Para group had worked at higher relative efforts (%MVIC) compared to the AB group at both RPE13 and 60W. This study highlights three considerations when comparing the sEMG of AB and Para participants.

First, the amplitude of the MVIC was not statistically different between the groups, but the Para group had a larger variability within the group. The MVIC method is known to be sensitive to the participants' ability to produce a maximal isometric contraction (Sinclair et al., 2015), which may be affected by the type of disability. The SENIAM protocol for collecting an MVIC for biceps brachii involves a co-contraction of the trunk muscles, which, to some degree, is impaired in individuals with paraplegia. This may account for the large variability in the MVIC in the Para group despite strict protocols for data collection. This study recruited individuals with Para, but large heterogeneity in the responses is a frequent limitation regarding Para participants and is often impossible to avoid completely. Researchers must therefore consider the nature of the disability in their population and how it may affect the participants ability to perform an accurate MVIC.

Second, the Para group produced a lower PO at a set RPE, and when the groups were matched for PO, the non-normalized excitation levels were similar. This highlights that the results are dependent on the purpose of the investigation, which should dictate whether subjective intensity (RPE) or matched power output should be used.

Third, both the low and high intensity dynamic methods yielded similar results for the RPE13 data, where there were no differences between the groups. This suggests that, when asked to work at a specific subjective intensity, the Para and AB individuals had similar levels of relative muscle excitation. Similar patterns were seen in the 60W data; however, the between-group differences were larger, with the Para group working at a slightly higher level of relative muscle excitation, although this did not reach statistical significance. Future research should examine whether these non-significant differences may have practical relevance for performance.

CONCLUSION: This study showed that, when comparing sEMG of Para and AB groups, there are considerations that researchers and practitioners must acknowledge when designing studies and training programs. Para athletes work at a lower PO at a given subjective RPE, which may affect any comparisons made with able-bodied athletes. It will also affect the amplitude of sEMG signals regardless of which normalization method is used to inspect the data. Further, differences in sEMG between Para and AB individuals may be disproportionally affected if normalized against an MVIC, since the nature of the disability may affect the MVIC measure.

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