ELECTROMYOGRAPHIC INTRA INDIVIDUAL VARIABILITY IN FRONT CRAWL SWIMMING

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The purpose of this study was to assess the intra-individual variability of two bilaterally measured EMG signals (deltoideus medialis and rectus abdominis) in front crawl swimming and compare the influence of the normalization technique on several variability measures. Fifteen well-trained adult male competitive swimmers were tested and four additional measures of variability besides mean and standard deviation were calculated. The repeatability of swimming movements was high for both tested muscles and one stroke cycle might be sufficient to determine a swimmers movement pattern. Variance ratio was suggested as a preferred additional measure of variability as it was least susceptible to differences in normalization method.

KEY WORDS: electromyography, swimming, variability.

INTRODUCTION: In the 50 year history of electromyographic (EMG) research in swimming, studies reported the mean (*M*) amplitude and the standard deviation (*SD*) as the sole measures of variability. Only one study evaluated the variability of myoelectric signals (Lewillie, 1976), but from “ten swimmers of different levels of ability”, only the results of one swimmer were presented. This author concluded that “the repeatability of swimming movements by highly skilled swimmers appears to be exceptionally high, as measured by both duration of and quantified electromyography” and that “a limited number of stroke cycles may therefore be accepted as valuable information.” No detailed information on the swimming protocol was given and only one muscle was analyzed (triceps brachii). In contrast to studies on gait (e.g. Burden et al., 2003), the influence of normalization on variability has never been investigated in swimming, despite the fact that 47 and 23% of the EMG studies use the maximum voluntary isometric contractions (MVIC) and dynamic methods to normalize and 30% use no normalization (Martens et al., 2014a). The purpose of this study was to assess the intra-individual variability of the EMG signal of two bilaterally measured muscles in front crawl swimming and compare the influence of the normalization technique on four variability measures.

METHODS: Fifteen adult male competitive swimmers (see Table 1) swam 3 x 25 m front crawl with a push-off start. In the first 12.5 m, swimmers accelerated to their maximal speed and breathing was allowed. During the last 12.5 m, maximal speed was maintained without breathing. EMG activity of the left and right rectus abdominis (RA) and deltoideus medialis (DM) was measured. Surface EMG was recorded using four channels of wireless EMG (KINE®) and electrodes were positioned and waterproofed as described previously (Martens et al., 2014b). The highest value of two 5 sec MVICs was determined for normalization. Two underwater stationary 50Hz video cameras (Sony Handycam HDR-HC9) were used to record the swimmers’ movements in their frontal and sagittal planes in the final 12 m window of each lap. Cameras were synchronized using Dartfish software (Dartfish Software Video Analysis 5.5) and to the EMG signal via a LED light connected to the EMG equipment. KINE Pro software (KINE Ltd., Hafnarfjördur, Iceland) was used for rectification and integration of the raw EMG signals.

Table 1
Overview of the subjects' characteristics (n = 15)

	M	*SD*
Age (yrs)	21.3	2.2
Height (cm)	186.6	5.5
Weight (kg)	79.1	8.0
Adipose tissue (%)	13.5	4.7
Arm span (cm)	193.8	6.9
Best time 100 m freestyle (sec)	54.7	1.9
Level (FINA points)	634.1	69.0
Number of years of competitive swimming experience (yrs)	11.9	3.2

Two full stroke cycles for both left and right upper limbs were analyzed from each of the three swimming trails. Stroke phases were determined using arm-water angles in the sagittal plane using Dartfish software. As stroke cycles have different timing both within each swimmer and between swimmers, multi-event synchronization for all selected stroke cycles (left and right separately) was obtained using Matlab R2012b software. For each measurement, the complete cycle was determined by a start and stop event (hand entry at 0° and 360°, respectively). These cycles were mapped to a 1000 %% (promille) time scale. Additionally, intermediate events (the angles determining the stroke phases) were synchronized to the mean timing of that event of all swimmers using a linear interpolation method. After this operation, the durations of both the complete stroke cycle, as well as each stroke phase, were equal for all swimming trails. Furthermore, two normalization techniques were used with Matlab R2012b software: (i) in the MVIC normalizing method, the highest value (in volts) found during the MVIC was considered 100% and (ii) in the normalization to the dynamic maximum, the highest value found during each swimming trail was considered 100%. To study the variability of the EMG signals, *M* and *SD* for the six cycles of each subject for all four muscles were calculated for the whole cycle and for each stroke phase. Coefficient of variation (CV in Eq. 1) was calculated as defined by Burden et al. (2003), as it allows the comparison of the variability of a data set with a larger and a smaller *M* and *SD*.

$$\text{CV (Burden)} = \frac{\sqrt{\frac{1}{k}\sum_{i=1}^{k}{\sigma_i}^2}}{\frac{1}{k}\sum_{i=1}^{k}|\bar{X}_i|} \qquad (1)$$

where *k* is the number of intervals over the stroke cycle (i.e. 1000), $\bar{X}_i$ is the mean of the EMG values at the *i*th interval calculated over the six cycles, σ_i is the *SD* of the EMG values about $\bar{X}_i$ calculated over the six cycles. When taking into account a time perspective, CV at the *i*th time interval was calculated as: $CV_i = \frac{\sigma_i}{\bar{X}_i}$.

The Mean value of 1000 CV_i's was defined as "**mean CV**". However, CV is influenced by the mean EMG value and could be overestimating variability in the sectors in which the muscle is not activated or is weak (Hug et al., 2008). For this reason, variance ratio (VR in Eq. 2) (Hershler and Milner, 1978), as well as mean deviation (MD in Eq. 3) (Hug et al., 2008), were calculated as extra measures of variability.

$$\text{VR} = \frac{\sum_{i=1}^{k}\sum_{j=1}^{n}(X_{ij}-\bar{X}_i)^2/k(n-1)}{\sum_{i=1}^{k}\sum_{j=1}^{n}(X_{ij}-\bar{X})^2/(kn-1)} \qquad (2) \qquad\qquad \text{MD} = \frac{\sum_{i=1}^{k}|\sigma_i|}{k} \qquad (3)$$

where *k* is the number of intervals over the stroke cycle (i.e. 1000), *n* is the number of cycles (i.e. 6), X_{ij} is the EMG value at the *i*th interval for the *j*th cycle, and $\bar{X}_i$ is the mean of the EMG values at the *i*th time interval over *j* stroke cycles. $\bar{X}$ is the mean of the EMG values, i.e. $\bar{X} = \frac{1}{k}\sum_{i=1}^{k}\bar{\bar{X}}_i$.

RESULTS: Examples of the muscle activity and variability of the right DM in six stroke cycles of two swimmers normalized to the MVIC are presented in Figure 1. The swimmer on the left panel showed the highest intra-individual variability expressed in terms of VR (0.50) of all subjects for this muscle. The swimmer on the right panel showed the lowest VR (0.19). Mean activation and SD, as well as CV expressed over the full stroke cycle, are also presented.

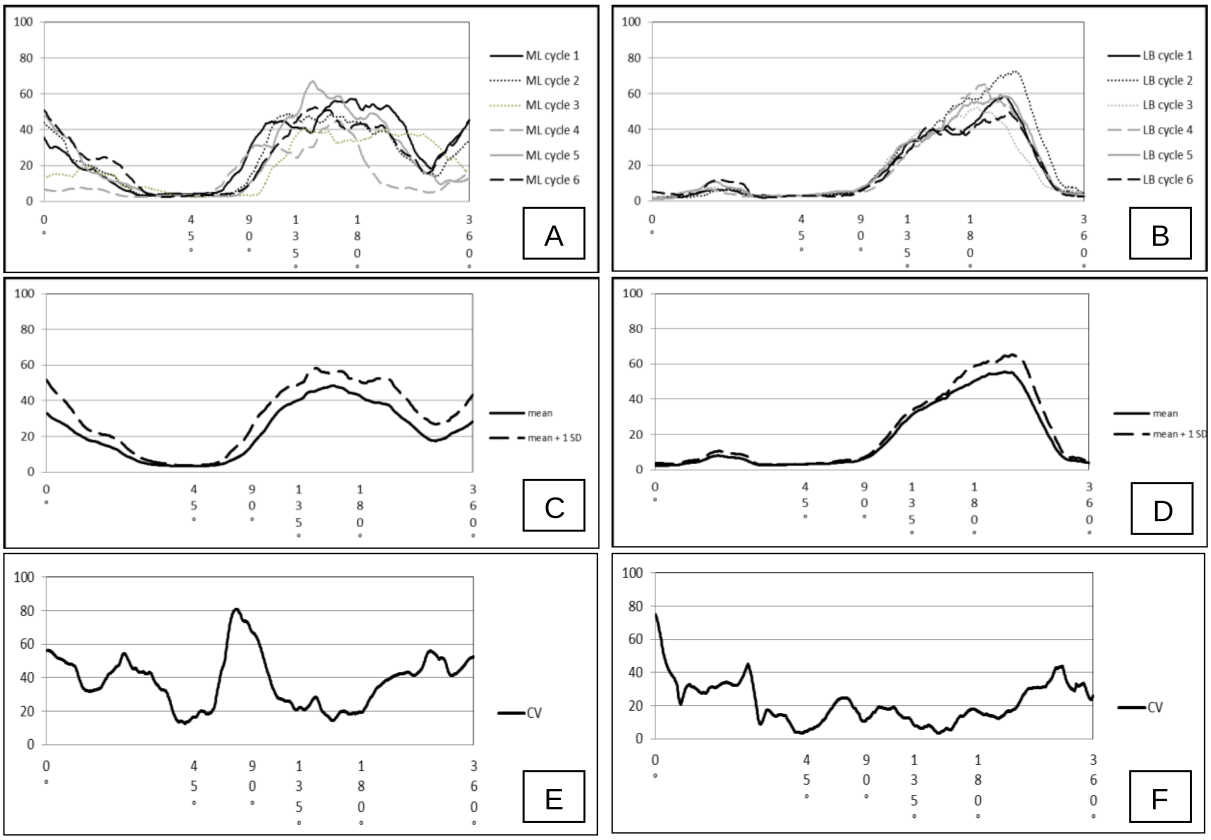

Figure 1: Muscle activity of the right deltoideus medialis of six stroke cycles of a swimmer with a high (A) and a low variance ratio (B). Mean activation and SD, and coefficient of variation for the swimmer with high (C, E) and low (D, F) variance ratio.

Table 2
Intra individual variability of swimming EMG's normalized using the MVIC and the dynamic maximum method averaged over 15 swimmers.

			Left DM	Right DM	Left RA	Right RA
MVIC	Mean CV	Mean	46.60	46.56 [a]	53.86 [a]	53.58 [a]
		SD	7.04	4.75	11.08	10.89
	CV (Burden)	Mean	0.52	0.52	0.77	0.76
		SD	0.07	0.07	0.17	0.17
	MD	Mean	11.51	11.46	4.38 [b]	4.28 [b]
		SD	2.53	2.43	1.72	1.54
	VR	Mean	0.34	0.35	0.46	0.47
		SD	0.09	0.09	0.16	0.15
Dynamic maximum	Mean CV	Mean	47.26	47.27 [a]	56.54 [a]	55.90 [a]
		SD	6.42	5.26	11.30	11.53
	CV (Burden)	Mean	0.52	0.52	0.75	0.73
		SD	0.07	0.07	0.16	0.17
	MD	Mean	10.44	10.47	8.82 [b]	8.76 [b]
		SD	2.06	2.23	2.25	1.77
	VR	Mean	0.34	0.35	0.46	0.46
		SD	0.09	0.09	0.16	0.15

Differences were found using a paired T-test ($P < 0.05$) in mean CV between the MVIC and dynamic maximum method (indicated in Table 2 by [a]), and in MD (indicated in Table 2 by [b]). All variability measures were different between the two muscles indicating a larger variability in RA, but no significant difference was found between left and right of each muscle.

DISCUSSION: This is the first study since 1976 to carry out an in-depth analysis of the variability of EMG in swimming. Four extra measures of variability were proposed. Studies that have been published since 1976 reported *M* and *SD* as sole measures of variability. The differences found between the two methods of normalization in mean CV and mean deviation could be due to the fact that these 2 measures are the most subject to differences in mean activation (and its *SD*). Since the maximal EMG values found in the MVIC method are larger than in the dynamic maximum one (Clarys, 1983), in all except one case, mean CV and MD are larger in the dynamic maximum condition. Figure 1 (panels E and F) evidences the overestimation of variability when using CV in the sectors in which the muscle showed low activity (Hug et al., 2008). In fact, VR has never been used before to assess intra-individual variability in DM and RA. In a study on gait analysis, VR values were found ranging from 0.51 to 0.76 in lower limb muscles when normalizing to MVIC (Burden et al., 2003).
The fact that no significant differences in variability were found between left and right in both muscles does not necessarily mean that the EMG patterns do not differ, but that these swimmers are equally stable in their movement pattern on both sides. Figure 1 (panels C and D) also shows inter-individual differences that need to be further investigated, since they might be the source of the high standard deviations (up to 52 % of MVIC) reported in amplitude studies of movement patterns in front crawl swimming (Pink et al., 1991).

CONCLUSION: The repeatability of swimming movements in well trained competitive swimmers is high for both DM and RA and one stroke cycle might be sufficient to determine a swimmers movement pattern. In future studies on EMG in swimming, in addition to *M* and *SD*, the variance ratio should be reported, as it was not susceptible to differences in normalization method. Inter-individual differences in activation do exist and need further investigation.

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