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Exteroceptive suppression of voluntary activity in thenar muscles by cutaneous stimulation: How many trials should be averaged?

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ABSTRACT

Objective: To determine a minimum number of trials that preserve input-output (I–O) properties of duration and magnitude of exteroceptive EMG suppression (eEMGs).
Patients and methods: eEMGs was recorded in 16 healthy subjects from thenar muscles following index finger stimulation at 2.5, 5, 10, and 20 times sensory threshold (xST). Individual trials were rectified and incrementally averaged in blocks of 5, 10, 20, 30, 40, 50, and 60. To determine if the block size affects I–O properties, the goodness of curve fit parameter R^2 for each block was compared to R^2 of the global function across all blocks combined.
Results: eEMGs was found in all subjects at 10xST and 20xST (100%, respectively) but less often at 5xST (63–75%) and 2.5xST (25–56%). A quadratic function best described both duration and magnitude of eEMGs. The quadratic R^2 did not significantly differ between any individual block function (5–60) and the global function (eEMGs duration 0.647-0.704 vs 0.679; magnitude 0.525–0.602 vs 0.560, respectively).
Conclusions: Averaging 5 trials consistently shows eEMGs at and above 10xST. I–O properties of eEMGs do not differ whether 5 or up to 60 trials are averaged. Clinical studies of eEMGs in thenar muscles are possible with as few as 5 trials averaged.

1. Introduction

Electrical stimulation of a mixed or cutaneous nerve during sustained muscle contraction results in transient suppression of voluntary activity. This is visible as a reduction or disappearance of voluntary EMG recorded from the active muscle (exteroceptive EMG suppression). Cutaneous nerve stimulation at low intensities elicits a cutaneomuscular reflex [1,2], which consists of a series of partially overlapping excitatory and inhibitory responses of spinal and supraspinal origin. An increase in cutaneous stimulation intensity from perception to pain threshold results in a progressively longer and more pronounced inhibition. Inhibition at or above the pain threshold is known as a cutaneous silent period (CSP), which is ascribed to a spinal inhibitory reflex [3]. High threshold (small fiber) afferents are primarily responsible for the electrically-induced CSP, with some contribution of low-threshold (large fiber) afferents (see review [4]). Lower threshold afferents presumably keep spinal inhibitory interneurons in the state of readiness to respond to additional input from higher threshold afferents, which ultimately inhibits spinal motor neurons.

The CSP has been widely studied in healthy subjects and more recently in pathologic conditions affecting various types of afferent fibers or the presumed spinal cord network (see review [5]). To distinguish between the involvement of low vs. high threshold afferents, it is customary to record a sensory nerve action potential (SNAP) to assess the status of low threshold skin afferents [3,6]. After obtaining the CSP by stimulation above the pain threshold, the SNAP and CSP results are interpreted together to infer the types of afferents affected. Since the recruitment of low vs. high threshold afferents depends on current intensity, another possibility is to examine their combined contribution to the exteroceptive EMG suppression by plotting an input-output (I–O) curve across the range of stimulation intensities, as customary in studies of cortical [7–9] and spinal [10] excitability. Besides initial demonstration that the magnitude of EMG suppression depends on the intensity of stimulation [11], only two previous studies examined the I–O curve in more detail; the first one to determine minimal stimulation intensity and duration required for eliciting CSP of maximal duration [12], and the second one to infer the contribution of low threshold afferents to the CSP duration [13]. To expand upon these observations,

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the first aim of this study was to examine and model the I–O properties of the exteroceptive EMG suppression, including the CSP, in a sample of healthy subjects.

One of the limitations for broader clinical use of the CSP is the practice of recording multiple trials at intensities above the pain threshold, which may cause significant discomfort. The number of trials recorded ranges from as few as 1 [13,14], 3 [15], 4 [16], 5 [17,18], 6 [19], or 10 [6] in clinical studies and from 3 [12], 10 [20], and up to 100 [9] in research studies (see also Ref. [4], Supplementary Table 3). This implies the lack of agreement as to how many trials should be averaged and the lack of justification for a given approach. The reason for such a large discrepancy is an assumption by clinicians that pathological changes may be captured with only a few trials recorded, whereas researchers tend to average many trials to improve the signal-to-noise ratio, as with evoked potentials or trans-cortical reflexes. In contrast to the latter responses, the CSP is robust and often visible on a single trial at sufficiently high stimulation intensities [16,18]. Moreover, averaging many trials may confound the CSP results since the excitatory trans-cortical reflex may appear early within the CSP window, particularly at lower intensities [9], making a determination of the onset latency ambiguous. From the standpoint of clinical practice, it is desired to deliver the least necessary number of stimuli to ensure subject cooperation and to perform studies in a time-efficient manner.

Determining the minimum number of trials that yield a reliable response may be approached statistically [21], However, interpretation of statistical estimates such as the intra-class correlation coefficient is not straightforward, because this measure of reliability is influenced by a spread of values in the dataset, making it prone to sample bias. Also, the adopted boundaries between different levels of reliability (e.g., “good” vs. “excellent”) are artificial, leaving the clinician with little practical guidance. A more prudent, physiologic approach would be to examine whether properties of the I–O curve representing the exteroceptive EMG suppression differ as a function of the number of trials averaged, which is the second aim of this study. With only a few trials averaged, the I–O curve may be impossible to adequately fit, or curves with a different number of averages may have different shapes or parameters (slope, intercept). Alternatively, if the I–O properties do not significantly differ between the curves with a small vs. a large number of trials averaged, it can be concluded that smaller averages capture the same information as larger averages, thus justifying the use of fewer trials. Assuming that many trials need to be averaged to adequately model the exteroceptive EMG suppression, we hypothesized that the parameters of I–O curve composed of fewer trials would significantly differ from the parameters of the I–O curve with more trials averaged. This was tested separately for the two most commonly reported parameters, the duration and magnitude of exteroceptive EMG inhibition.

2. Material and methods

2.1. Subjects and procedure

Sixteen healthy subjects (mean age 41 ± 11 years, 9 men) with no known neurological disorders signed the informed consent to participate in this study approved by the Institutional Review Board of Methodist Rehabilitation Center. Subjects were seated upright in a comfortable chair. The dominant arm was positioned on an armrest, with the shoulder in a neutral position, the elbow at a 90° angle, the hand slightly pronated, and the digits relaxed.

Routine electrodiagnostic equipment (Viking Select, Viasys, Madison, WI, USA) was used for stimulation and recording. Ring electrodes were placed around the two distal phalanges of the index finger. Sensory threshold (ST) was determined using constant current square wave pulses of 0.5 ms duration [9]. A pair of surface recording electrodes (distance 3 cm) was placed over the belly and tendon of the ipsilateral thenar muscles.

Subjects were asked to hold steady thumb abduction at 20–25% of maximum effort against a velcro-strap. The force was not monitored since it does not critically influence CSP parameters below 50% of the maximum [9,22,23]. Auditory feedback was provided to facilitate the maintenance of constant effort during the recording.

Exteroceptive EMG suppression was induced by delivering repetitive square wave pulses (0.5 ms duration, 0.7 Hz rate) in blocks of 60 stimuli. The intensity (2.5, 5, 10, and 20xST) was varied between blocks in random order. Single sweeps of 1000 ms in duration, including 100 ms pre-stimulus delay, of the non-rectified surface EMG were recorded (sampling rate 2000/s), amplified, and filtered (band-pass 30–10,000 Hz).

2.2. Data processing

Individual waveforms were imported into custom-made MATLAB software (MathWorks, Inc., Natick, MA, USA) for further processing and analysis. The waveforms were rectified and incrementally averaged in blocks of 5, 10, 20, 30, 40, 50, and 60 trials for each subject. For each block and subject, the mean rectified EMG amplitude was calculated over the 100 ms pre-stimulus interval (baseline) and the 80% cut-off was determined (Fig. 1). The software identified the onset and end latencies of the exteroceptive EMG suppression by searching from 80 ms after the stimulation (typical mid-point of the CSP) in both directions for the last 4 and the first 4 consecutive points above the 80% cut-off. The onset latency was defined as the intersection between the 80% pre-stimulus baseline and the line that connects the last of the 4 consecutive points above the cut-off and the first point below the cut-off. The end latency was similarly defined as the intersection between the 80% pre-stimulus baseline and the line that connects the last point below the cut-off and first of the 4 consecutive points above the cut-off. The duration of exteroceptive EMG suppression (ms) was calculated as the difference between the end and onset latencies. The magnitude was expressed as the suppression index (SI, %), derived by dividing the mean EMG amplitude corresponding to the duration of inhibition by the mean EMG amplitude during the pre-stimulus baseline (the smaller the SI, the greater the suppression). The software allowed for visual inspection of the averaged waveforms and adjustment of starting search points, if necessary. All averaged waveforms were independently inspected by two authors who verified the proper marker placement. The duration

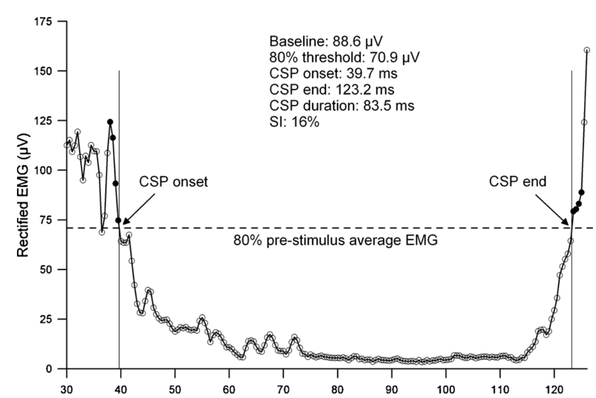

Fig. 1. The average waveform from a single subject (block of 20 trials, 20xST) depicts the method for software analysis. The onset and end (arrows) of exteroceptive EMG suppression are defined as the intersection between the broken line that represents 80% of the pre-stimulus baseline and the solid line that connects the points above and below the 80% of baseline. The point above the 80% baseline is selected by the software as the first of the 4 consecutive points above the cut-off on each side of the window (black circles). Vertical lines from the intersections down mark the onset and end latencies read by the software with subsequent calculation of the duration and index of suppression (SI).

and SI for each of the 7 blocks of averaged trials per subjects were exported into a spreadsheet. If the EMG suppression did not meet the above definition, a 0-ms value was imputed for the duration and 100% for the SI (i.e., average EMG during the selected inhibitory window equal to the pre-stimulus baseline).

2.3. Statistical analysis

The duration and SI values were submitted to GraphPad software for further analysis. First, the prevalence of EMG suppression was analyzed across different blocks and stimulus intensities. Then, the duration and SI were compared across different blocks using both imputed and non-imputed data (reported as mean ± SE).

The I–O curve fitting was done on imputed dataset because this way all subjects contributed data to all blocks (balanced design) and the derived models can serve as normative data for comparison to patient groups. The most parsimonious and physiologically plausible model with the highest coefficient of determination (R^2) was considered the best fit. The following procedure was used to determine the performance of the best-fit models. The Replicates test was run first to determine whether the best solution follows the data trend (i.e., how far are the points from the curve compared to the scatter of replicates). In the second step, the Extra sum-of-squares F-test was used to determine whether the block size (i.e., the number of trials averaged) affects curve parameters. This was done by testing whether a single global curve accounting for all blocks together provides an adequate fit as do the individual curves for each block separately. That is, if the parameters of the global curve do not statistically differ from the parameters of each individual curve, it is concluded that block size (number of trials averaged) does not influence the properties of I–O curve, thus rejecting the stated hypothesis. Conversely, if the parameters of the global and individual curves differ significantly, the properties of I–O curve are affected by the block size and the stated hypothesis was accepted. A p-value of < 0.05 was considered significant.

3. Results

3.1. Characteristics of exteroceptive EMG suppression with 5–60 trials averaged

The prevalence of exteroceptive EMG suppression increased more with increasing stimulus intensity than with the number of trials averaged. Across all 16 subjects and 7 blocks per subject (total 112 blocks per stimulus intensity), the EMG suppression as defined here was present in 48 (43%) blocks at 2.5xST, 81 (72%) blocks at 5xST, and in all 112 blocks (100%) at 10 and 20xST. When the EMG suppression was absent at 5xST, it was also absent at 2.5xST in the same block and subject, except on two occasions. As a result, the prevalence of EMG suppression was 25% (4/16 subjects) at 2.5xST with 5 or 10 trials averaged, which increased to 56% (9/16 subjects) with 50 and 60 trials averaged (Table 1). This increase in prevalence at 2.5xST was not significantly different between blocks of 5 and 60 (Fisher's exact test, p = 0.149). At 5xST the prevalence ranged from 63% to 75%, and at 10 and 20xST, it reached 100% (EMG suppression present in all 16 subjects across all blocks). The least number of trials that produced the EMG suppression in all subjects was 5 trials at 10xST. The waveforms from a subject with suppression across all stimulation intensities and blocks are shown in Fig. 2.

Table 2 shows the means for the duration and magnitude (SI) of EMG suppression across all blocks and stimulation intensities (0 ms and 100% imputed if no suppression found). At 2.5xST, the mean duration increased from 9 ms for the blocks of 5 and 10 averages to 16 ms for the blocks of 50 and 60 averages (not significant, paired t-test). At 5xST and above, the difference in duration of EMG suppression was also not significant across different block sizes. If the analyses for 2.5 and 5xST included only data when the EMG suppression was present (non-imputed data), the mean duration at 2.5xST ranged from 38 ms for the block of 5 averages to 29 ms for the block of 60 averages, and at 5xST from 52 to 48 ms, respectively, (both not significant, unpaired t-test).

Table 1
Number (percent) of subjects out of 16 in whom the exteroceptive EMG suppression was elicited in each block across different stimulus intensities (ST, sensory threshold).

Block (*n*)	Stimulus intensity (xST)			
	2.5	5	10	20
5	4 (25%)	10 (63%)	16 (100%)	16 (100%)
10	4 (25%)	11 (69%)	16 (100%)	16 (100%)
20	7 (44%)	12 (75%)	16 (100%)	16 (100%)
30	7 (44%)	12 (75%)	16 (100%)	16 (100%)
40	8 (50%)	12 (75%)	16 (100%)	16 (100%)
50	9 (56%)	12 (75%)	16 (100%)	16 (100%)
60	9 (56%)	12 (75%)	16 (100%)	16 (100%)

No significant difference between blocks of 5 and 60 at both 2.5 and 5xST (Fisher's exact test, p ≥ 0.149).

In terms of the magnitude of EMG suppression, mean SI decreased with increasing stimulation intensity, from about 80% of pre-stimulus baseline at 2.5xST to about 25% at 20xST (Table 2, bottom part). The SI was not significantly different between the blocks with a different number of trials averaged for any stimulation intensity when a 100% value was imputed to the cases not meeting the definition of suppression. If analyses included only data with the EMG suppression present (non-imputed dataset), the mean SI at 2.5xST was significantly different between the blocks of 5 (39%) and 60 averages (63%, p < 0.05, Bonferroni multiple comparison test), but not at 5xST (42% and 55%, respectively).

3.2. Input-output properties of exteroceptive EMG suppression

The I–O curve of exteroceptive EMG suppression was fitted to the imputed data for the reasons stated in the methods. The best fit for the duration of EMG suppression was the second order polynomial (quadratic) function. The statistical results indicated that a global quadratic function, derived from all blocks together, provided a fit that was as good as from the individual functions representing each block separately (Replicates test F = 0.00–0.56, 0.81 ≤ p ≤ 0.98; Extra sum-of-squares test F = 0.196, p = 0.999). This rejects the hypothesis that I–O curves for the duration of exteroceptive EMG suppression differ depending on the number of trials averaged. Table 3 shows the parameters of quadratic functions and the associated R^2 coefficients when each block (5, 10, etc.) was fitted with a separate function and when all blocks (5–60) were fitted in aggregate with one global function (bottom row, shared R^2 = 0.679). In addition, the last column provides the R^2 values when each block was fitted with the global function for comparison to the R^2 values of the respective individual functions (preceding column). Note small differences between the global and individual R^2 values across all blocks (0.003 when the global shared R^2 is subtracted from the mean of individual R^2 values). Fig. 3 shows the average duration of exteroceptive EMG suppression for different blocks and stimulation intensities along with the I–O curve of the global function, demonstrating adequate fit to the data.

The results for the SI were similar. The quadratic function also provided the best fit but the R^2 values were somewhat lower (Table 4). Again, there was no statistical difference between the individual and global fit with respect to the number of trials averaged (Replicates test F = 0.22–1.4, 0.25 ≤ p ≤ 0.79; Extra sum-of-squares F-test F = 0.21, p = 0.998). The shared R^2 of the global function was 0.56 and similar to the R^2 values of the individual functions. The difference between the global R^2 value and the mean of the individual R^2 values was 0.004. Fig. 4 shows the mean SI for different blocks and stimulation intensities along with the I–O curve of the global function demonstrating overall

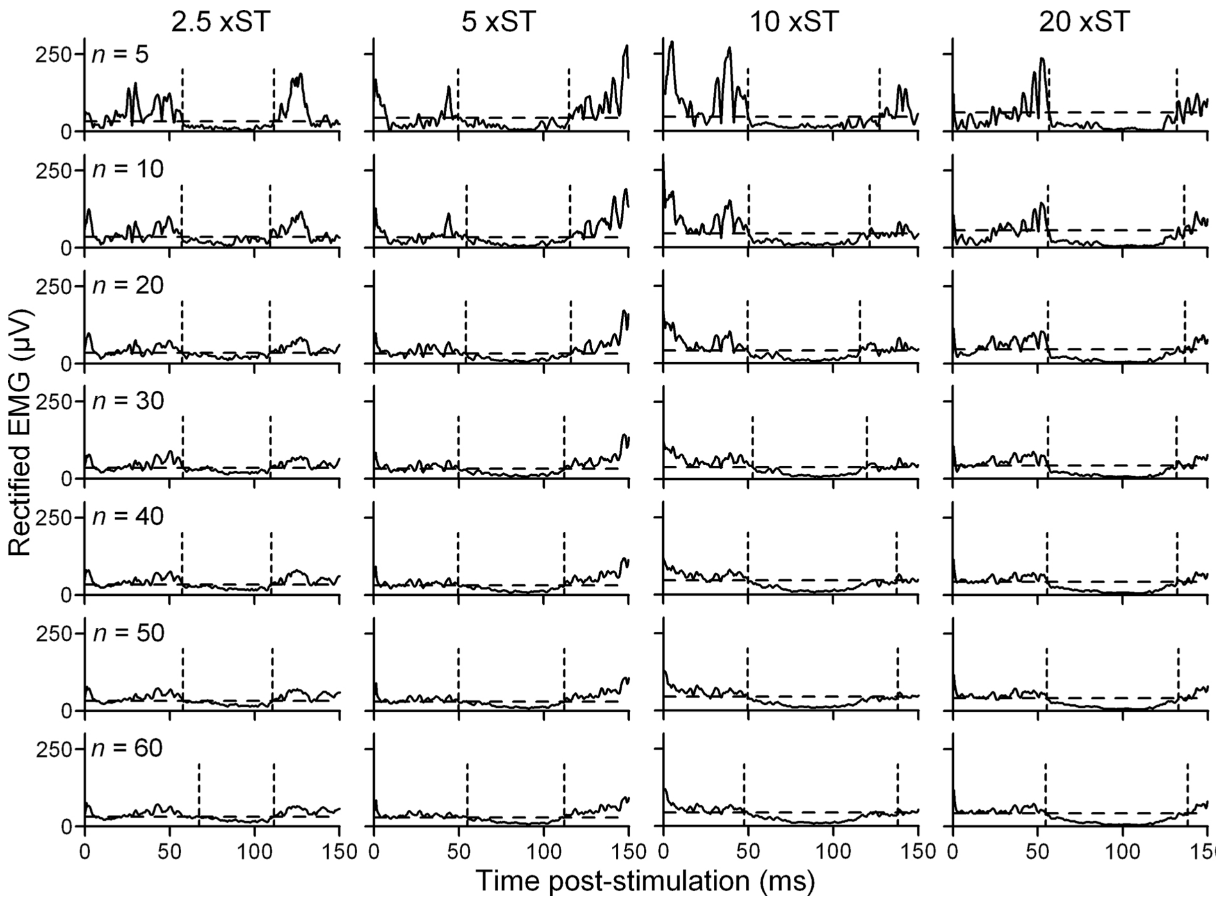

Fig. 2. The waveforms from a subject with unusually long exteroceptive EMG suppression at low stimulation intensity (2.5xST) that increased more in magnitude than duration at higher intensities (5–20 × ST). Note no major differences across 7 blocks (rows) of the incrementally larger number of trials averaged (*n* = 5–60) at any stimulation intensity. The broken horizontal line indicates 80% of pre-stimulus baseline and the two vertical lines denote the onset and end of EMG suppression.

Table 2
Mean (± SE) for the duration and magnitude of exteroceptive EMG suppression for each block across different stimulus intensities (ST, sensory threshold). If absence of suppression, values of 0 ms for duration and 100% for index of suppression were imputed.

Block (*n*)	Stimulus intensity (xST)			
	2.5	5	10	20
Duration (ms)				
5	9.3 ± 4.6	32.8 ± 3.3	64.3 ± 6.6	93.1 ± 5.3
10	9.4 ± 4.3	32.9 ± 6.9	68.9 ± 6.4	94.7 ± 4.2
20	12.9 ± 4.2	35.7 ± 6.4	69.1 ± 6.5	98.9 ± 4.3
30	13.0 ± 3.9	35.4 ± 6.3	68.1 ± 6.2	95.8 ± 4.1
40	15.0 ± 4.3	35.1 ± 6.6	66.6 ± 6.4	96.7 ± 4.5
50	16.9 ± 4.4	36.6 ± 6.7	69.5 ± 6.0	94.0 ± 4.3
60	16.3 ± 4.2	35.8 ± 6.6	69.3 ± 6.1	94.2 ± 4.2
Index of Suppression (%)				
5	84.8 ± 6.9	64.0 ± 8.1	33.7 ± 4.4	23.5 ± 1.5
10	87.0 ± 5.9	59.2 ± 7.2	35.5 ± 4.6	24.9 ± 1.7
20	81.7 ± 5.5	66.4 ± 6.6	37.2 ± 3.6	27.1 ± 1.8
30	81.3 ± 5.6	61.0 ± 6.3	40.1 ± 4.8	25.5 ± 1.5
40	79.6 ± 5.4	62.9 ± 6.1	37.3 ± 3.4	25.8 ± 1.2
50	79.0 ± 4.9	63.9 ± 6.0	40.6 ± 4.7	24.9 ± 1.4
60	79.1 ± 4.9	65.9 ± 6.1	40.9 ± 4.7	27.7 ± 3.1

Index of Suppression expressed as a percent of pre-stimulus baseline.

adequate fit. The results did not substantially differ when the same analysis was done on the non-imputed dataset (best fit with the quadratic function, no significant difference between the global fit and each individual fit, slightly smaller R^2 values).

Table 3
Parameters of the quadratic function ($Y = a + b*X + c*X^2$) that best fitted the duration of exteroceptive EMG suppresion data taking into account each size set separately (5–60) and all sets together (global). The last two columns provide a comparison of the goodness of fit (R^2) between each individual solution and the global solution fitted to the same block size (note comparable R^2 values).

Block (n)	Parameters of quadratic function for duration of EMG suppression				
	a	b	c	Individual R^2	Global R^2
5	−0.0141	0.0105	−0.0003	0.647	0.641
10	−0.0182	0.0118	−0.0003	0.695	0.692
20	−0.0120	0.0107	−0.0003	0.704	0.702
30	−0.0117	0.0106	−0.0003	0.704	0.704
40	−0.0077	0.0096	−0.0002	0.675	0.674
50	−0.0075	0.0103	−0.0003	0.664	0.661
60	−0.0084	0.0103	−0.0003	0.675	0.673
Global	−0.0114	0.0105	−0.0003	–	0.679[a]

[a] shared R^2 of the global function.

4. Discussion

This study of exteroceptive EMG suppression in the thenar muscles elicited by cutaneous stimulation of the index finger revealed two major findings. First, the suppression is present in all healthy subjects at ≥10xST with only 5 trials averaged. Secondly, the pattern of progressively longer and greater suppression with increasing stimulation from 2.5 to 20xST is adequately described whether as few as 5 or up to 60 trials were averaged at each intensity. These results have several implications.

A major concern in many CSP studies has been the use of high-

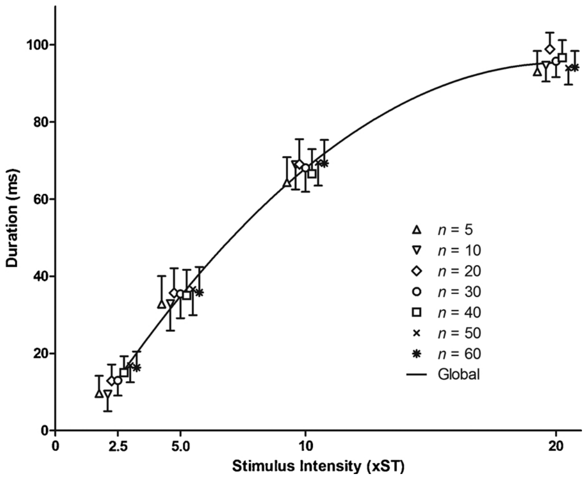

Fig. 3. Mean values (± SE) for the duration of exteroceptive EMG suppression for blocks with the different number of trials averaged (*n* = 5–60) and the global input-output curve fitted to all data (data points offset for visibility).

Table 4
Parameters of the quadratic function (Y = a + b*X + c*X^2) that best fitted the magnitude of exteroceptive EMG suppression data taking into account each size set separately (5–60) and all sets together (global). The last two columns provide a comparison of the goodness of fit (R^2) between each individual solution and the global solution fitted to the same block size (note comparable R^2 values).

Block (n)	Parameters of quadratic function for magnitude of EMG suppression				
	a	b	c	Individual R^2	Global R^2
5	1.090	−0.107	0.002	0.525	0.519
10	1.104	−0.111	0.003	0.573	0.566
20	1.045	−0.094	0.003	0.584	0.583
30	0.996	−0.085	0.002	0.553	0.552
40	1.003	−0.088	0.003	0.602	0.601
50	0.969	−0.077	0.002	0.580	0.575
60	0.974	−0.078	0.002	0.546	0.539
Global	1.026	−0.091	0.003	–	0.560[a]

[a] shared R^2 for the global function.

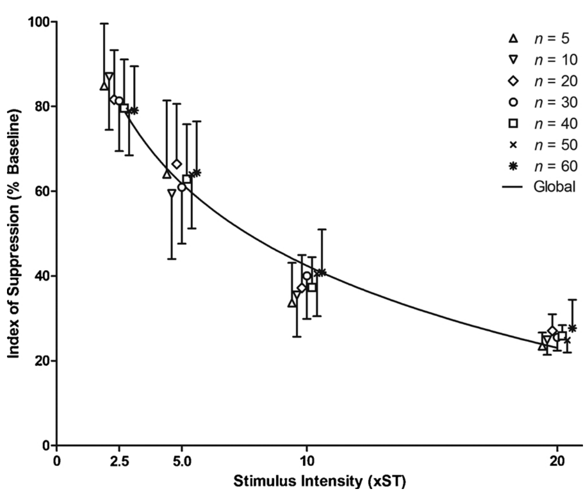

Fig. 4. Mean values (± SE) for the index of exteroceptive EMG suppression for blocks with the different number of trials averaged (*n* = 5–60) and the global input-output curve fitted to all data (data points offset for visibility).

intensity stimulation over many trials, which often limited the tolerance. The results of this study suggest that the need to record fewer trials could help to increase overall subject compliance and acceptance of the technique by clinicians and scientists. This is of particular interest as the clinical utility of CSP technique has recently gained some attention [5].

The most salient finding of this study is that averaging 5 trials at 10xST is sufficient to evoke in healthy subjects the exteroceptive EMG suppression below 80% of pre-stimulus baseline. Thus, *not* attaining this level of EMG suppression in thenar muscles following index finger stimulation at 10xST and above should be considered abnormal in an individual patient, which can be reliably detected after averaging as few as 5 trials.

In clinical research, the reported prevalence can be used as normative data for comparison of presence/absence of the EMG suppression between patients and controls. The prevalence of exteroceptive EMG suppression was found directly related to the stimulation intensity, as reported before [9,23] Of relevance here is that EMG suppression was present in all 16 subjects at and above 10xST regardless of whether 5 or 60 trials were averaged. Although the prevalence at 2.5xST more than doubled when the number of averages increased from 5 to above 40 (Table 1), this difference was not significant. Such an increase is in contrast to the reported habituation at 2xST and 3 Hz repetition rate [13], which can be explained by a lower repetition rate in our study (0.7 Hz).

The frequent absence of EMG suppression at low intensities may be due to insufficient activation of small A-delta fibers responsible for generating the CSP or pronounced recruitment of large myelinated fibers producing a long-latency excitatory reflex that may be interposed between the early and late periods of inhibition [9]. This may cause EMG to remain above the level that defines the onset and end of exteroceptive EMG suppression (80% of pre-stimulus baseline here). For a comparable number of trials averaged, the EMG suppression was evoked here at a similar rate as in the previous studies that defined the presence of inhibition (CSP) in the same manner [9,23].

The number of trials averaged did not affect the duration or magnitude of EMG suppression with stimulation intensities at or above 5xST. At 2.5xST, the duration somewhat increased, albeit non-significantly, from the block of 5 averages to the blocks of 40–60 averages when 0 ms was imputed to the cases not meeting the definition of suppression (Table 2). What lies behind, is the increased prevalence of suppression from 5 to 60 averages; with more 0-ms imputed values replaced by actual durations, the means become larger. However, if analyzing only the data when the suppression was present (non-imputed dataset), the mean duration *decreased* (~10 ms) non-significantly from 5 to 60 averages. Similar to the duration, the number of trials averaged did not affect the magnitude of suppression at 2.5 ST across different stimulation intensities in the imputed dataset (Table 2). In the non-imputed dataset, significantly *less* suppression (25% difference) was found with an increase from 5 to 60 averages. The *decrease* in both the duration and magnitude of suppression at 2.5xST is likely due to the increase in the excitatory component of trans-cortical reflex with more trials averaged.

The uncertainty about the number of trials to be averaged could be overcome by examining the I–O curve between the stimulus intensity and the duration and magnitude of exteroceptive EMG suppression. The I–O results reported here re-affirm some known findings, but also reveal new ones. Several investigators reported a longer and more profound EMG suppression with increasing stimulus intensity [9,11,12,23] but the profile of change has not been studied in detail. We found that the duration and magnitude of exteroceptive EMG suppression were best fitted with a quadratic function (increasing and decreasing, respectively). The overall goodness of fit (R^2) was somewhat better for the duration than the magnitude (Tables 3 and 4). This can be ascribed to typically smaller inter-individual differences in latency (hence duration) vs. amplitude measures in neurophysiologic recordings. The adequate performance of each model is re-affirmed by the intercept (parameter “a”), which approximates 0 for the duration and 1 for SI, partially reflecting the impact of imputed values due to low prevalence of the EMG suppression at 2.5xST.

Of practical relevance is the finding that averaging a smaller number of trials did not affect the properties of I–O curve best representing the duration and magnitude of exteroceptive EMG suppression. For both parameters, the global model fitted the data as adequately as did each individual model for averages from 5 to 60 trials. This is also evident as a negligible difference between the R^2 values when the global function or separate individual functions were fitted to each block of data for both the duration and magnitude of EMG suppression (Tables 3 and 4). Such findings can be attributed to well-known characteristics of exteroceptive EMG suppression on both ends of the examined I–O relationship; that is, the frequent absence of inhibition at low stimulation intensities and the consistent presence of profound inhibition at higher stimulus intensities, commonly seen even in individual traces [16]. Thus, in healthy subjects, properties of the I–O curve representing exteroceptive EMG suppression do not substantially change whether only a few or many trials are averaged. The overall results suggest that averaging as few as 5 or up to 20 trials should be adequate, depending on the nature of the study, sample size, and judgment of investigators. Interpreting the changes in the I–O properties of the duration and magnitude together may help to better understand mechanisms involved in low versus high stimulation intensity exteroceptive EMG suppression [24,25] and explain some less intuitive CSP findings [26,27].

4.1. Study limitations

Only the index finger-thenar muscle combination was examined here; thus, it remains to be seen how the current results compare to other digit-muscle pairs, although no major difference is expected. The results are based on fitting the curve to the entire study sample, thus, caution should be exercised when using these normative data to determine whether a single case differs from controls. Although the sample size is relatively small, the exteroceptive EMG suppression was robust and showed typical characteristics, which provides confidence in the generalization of the findings. Until tested in real-life situations, the applicability of the described analysis method remains speculative. In any case, this approach should be considered complementary to other evaluation methods. Its practicality may also be of concern. However, we will provide the software upon the request free of charge or alternatively, the waveform analysis and the curve fitting can easily be done in the spreadsheet software. The parameters of the curves shown for healthy subjects can be used for comparison with patient groups for research purposes. The most practical application of this study, ready for immediate use in clinical practice, is the finding that 5 traces at 10xST are sufficient to produce the suppression below 80% of the baseline in all healthy subjects, which can serve as a normative data for comparison to individual patients. Since nearly all EMG equipment used in clinical settings is capable of rectifying and averaging traces online as well as calculating the area under the curve, the analysis of presence/absence of suppression is the most practical application of our results.

5. Conclusion

Exteroceptive EMG suppression is present in all healthy subjects at 10xST after averaging only 5 trials. Moreover, averaging as few as 5 trials across the range of stimulus intensities yields I–O properties that are no different from averages containing as many as 60 trails. The possibility to record fewer trials than typically used before is expected to increase the compliance of patients and research subjects and efficiency in data collection.

Disclosure

None

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