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The trade-off between meticulousness and methodological variance in normalization of low back EMG

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Abstract. Background: Normalization of surface electromyography (EMG) is a common and recommended practice, however this methodological step itself introduces variability to a data set. Quantification of this variance is necessary to correctly interpret overall EMG variability. This information is also paramount to identifying experimentally and clinically relevant normalization task(s) which minimize induced variance yet are time-efficient. Purpose: The goal of this study was to quantify the within-day variance of two commonly reported, sub-maximal tasks utilised for low back EMG normalization: one collected with a high degree of meticulousness, and the other collected in a more rapid manner. Results: Only minimal differences were seen between tasks in the magnitude of within-day variance for EMG amplitude at all recording sites, save the right-side L5 location, which showed a significant difference (p=0.020). For trunk posture, within-day variance for the highly meticulous tasks was significantly higher than for the less-meticulous task (p=0.011). Conclusion: A less meticulous sub-maximal normalization task performed in a standing position was equal or superior to a more meticulously collected task in terms of kinematic task repeatability and within-day EMG variance. These findings are encouraging for field study applications where meticulous methods are not feasible, and provide a time saving strategy for lab studies.

Keywords: variance components, electromyography, work related musculoskeletal disorders, exposure assessment, submaximal

1. Introduction

Normalization of electromyography (EMG) signals serves to reduce many sources of variability irrelevant to the force production of the sampled muscle, for example: thickness of subcutaneous tissue, skin impedance, electrode placement, and distribution of active muscle fibres within the muscle [7,9,10,14]. Normalization also serves to transform signal measures from an arbitrary electrical scale to a standardized scale based on a physiological meaningful event, that is, to scale the output signal to the magnitude of muscle activation resulting from a known posture at specific level of exertion (most commonly, a maximal effort). For ergonomic applications, normalization of surface electromyography (EMG) is a common and recommended practice [14,20] which permits comparison between subjects and within subjects across days within a study. If comparable procedures are utilised, normalization also permits comparison of data between studies.

It is, however, paramount to note that the methodological step of normalizing EMG data will itself introduce variability to a data set. If the variance introduced by normalization is smaller than the eliminated 'irrelevant' variance, then normalization would seem a good trade off; however, normalization would not, from a statistical point of view, be a good idea if the variance introduced by normalization is larger than the corresponding reduction in "anatomical" variance; this undesired trade-off has previously been

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both theorized [21], and shown to occur experimentally in some cases [18].

A clear idea about the size of the methodological variance is paramount for both experimental design and for correct interpretation of experimental data [3,15]. Most often, normalization induced variance is embedded in this overall variability of an EMG signal and is therefore erroneously interpreted as (part of) a 'true' biological variability between or within subjects due to work or personal factors. If the relative magnitude of the variance attributable to normalization is large relative to the magnitude of the biological variance, then it is possible that normalization could obscure or mar the interpretation of study findings. Thus, in order to understand the potential for reduced exposure variability, and hence improved statistical performance of a data collection, both methodological and biological sources of variance must be quantified and compared. To date, this has seldom been considered in the literature.

A single study was found which quantitatively assessed the unique component of variance induced through normalization and its relative magnitude to other sources of variance between and within studies [11]. In this study of trapezius muscle activity collected from female workers performing light, cyclic assembly work, the unique magnitudes of variance were calculated between subjects, between days within subject, and between cycles and normalization trial repeats within day. The unique contribution of normalization, *per se,* was shown to be between 0.5 and 4.4 % of the total variability across the seven calculated EMG exposure parameters. Interestingly, the variance attributable to normalization exceeded that of the cycle-to-cycle variance for several commonly reported, mid-range exposure variables, including the median and the 90th percentile of the cumulative amplitude distribution. No further studies were found that quantified the unique variance component introduced by normalization in any other anatomical areas. Further, no comparison of the relative sizes of the variances introduced using different normalization tasks or degrees of meticulousness in collecting trials were found for any anatomical region.

Traditionally, EMG studies of the lumbar spine musculature were conducted during manual materials handling tasks and therefore involved relatively high muscle activation levels. With modern industrialization, however, a strong trend has occurred towards occupations requiring prolonged seated work involving prolonged, low level muscle activations, thus altering typical occupational low back loading paradigms. In the last decade concerted efforts have been made to understand the mechanisms behind low level exposures and worker discomfort. Several research groups have reported EMG levels from the erector spinae (ES) muscles in the lumbar region during low level occupational tasks with values ranging from 1 – 6% MVC (maximum voluntary contraction) including: quiet seated work conducted with back support [1,12,17], without back support [4,17], and without back support while sitting on an unstable surface, such as a Swiss ball [12,17]. In each of these studies, the magnitude of difference in EMG between test conditions/groups has ranged from 0,5 – 1,5% MVC; test conditions have included chair type [12,17], subject pain level, healthy control versus pained[13], and within subject comparisons of muscle activation level before and after seated exposures[4]. In some studies, this magnitude of difference has proven to be significant between groups or conditions [4,12,13] while other studies have not found the difference to be significant [17]. Common to all of these studies is the lack of quantification of measurement error and the relationship between this magnitude of measurement error and measured signal. Arguable, this is increasingly problematic given the emphasis on tasks involving such small differences between low levels of EMG and hence the likelihood of an increase in the relative size of the methodological variance compared to the biological variance.

Amongst studies reporting normalized muscle activation levels in the lumbar spine region, the literature indicates a wide range of both gross body postures (seated, prone and standing) and exertion levels (from sub-maximal to maximal) during normalization tasks. Varying methods and degrees of care have been reported for positioning and maintaining subjects in a selected test posture. The effect of meticulous normalization practices during data collection is, to date, also unknown; that is, how much precision can be gained with extra time and/or effort while collecting normalization trials. This information would be beneficial to identify experimentally and clinically relevant normalization task(s) and practices which minimize the amount of variance introduced while also being time-efficient.

The purpose of this study was therefore to quantify the within-day variance of two commonly reported, sub-maximal normalization tasks for low back EMG: one task collected with a high degree of meticulousness in regards to trunk position, and the other collected in a more rapid and less careful manner, similar to what might be feasible in a field-based study.

2. Methods

Data utilized in this study were collected as part of a larger study examining ten sub-maximal and three maximal normalization tasks and the effect of normalization method on exposure assessment metrics during cyclic manual materials handling tasks.

2.1. Participants

Male participants, ages 18 – 55, were recruited from the greater Boston area. All potential participants completed a health questionnaire; potential participants were excluded if they reported a history of chronic low back pain (LBP), had experienced LBP in the preceding 12 months, or had any other medical conditions that would prevent them from working a typical manual materials handling job over an eight hour shift. In addition, participants were excluded if their body mass index (BMI) was in excess of 30, which corresponds to the 'obese' category; this criterion was selected to maximize EMG signal quality. From the pool of potential participants who cleared the health screening, those with prior manual materials handling experience were preferentially recruited. All participants reviewed and signed an information and consent form which outlined the experimental protocol and which had been approved by both the Internal Review Board at the Liberty Mutual Research Institute for Safety and the Office of Research at the University of Waterloo.

The fifteen male participants who completed the study had mean height 1.78 m (SD 0.11, range 1.52 – 1.93), mean weight 79.6 kg (SD 13.2, range 52.3 – 97.7), and mean BMI 25.1 kg*m^{-2} (SD 3.5, range 20.1 – 29.8).

2.2. Study protocol

The study involved a three day protocol, with at least one day between scheduled visits. On the first experimental day, participants were introduced to the difference between hip flexion and lumbar spine flexion and performed both movements until both the experimenter and participant believed the participant understood the difference. Next, the participant was introduced to, and practiced each of the normalization tasks involved in the larger study, including the two normalization tasks utilized for the current study. Once the participant indicated they felt comfortable performing a normalization task they proceeded to learning the next task. After all normalization tasks had been practiced, the participant was given a break of at least 30 minutes; from this point forward, the protocol followed was the same for all experimental days.

On each experimental day participants were instrumented with EMG electrodes and motion capture markers, and a subject specific motion capture template was created. Next, participants performed 10 cycles of a manual materials handling task as a warm up before commencing the normalization task trials. Normalization tasks were presented in a block-randomized order where gross body posture (sit, stand, prone) formed the blocks. Tasks within body posture block were also randomized. Participants completed four sequential repeats of each task with rest allotted between each trial repeat and also between tasks.

2.3. Normalization tasks

The two normalization tasks specific to the current paper were sub-maximal, reference voluntary exertions, at both a meticulously measured trunk angle (M-RVE), and at an 'eye-balled' trunk angle (EB-RVE). In both tasks participants stood in approximately 50° hip flexion while holding a 10 kg weight in the hands, arms hanging vertically – Figure 1. In M-RVE trials the participant was guided to 50° flexion by an investigator using a digital inclinometer aligned along the vertical axis of the trunk, while in the EB-RVE trials participants were verbally guided to the posture by an investigator who visually matched the participant to a line at 50° marked on the wall behind the participant – Figure 1. Once the participant had reached the experimental position, a 10 s file was collected.

2.4. Experimental measures

On the first experimental day, bilateral muscle recording sites were identified using anatomical landmarks for the thoracic ES at the level of the ninth thoracic vertebrae (T9) level [16], and in two locations along the lumbar portion of the ES – at the level of the first [16] and fifth lumbar vertebrae [5](L1 and L5, respectively). At each site, the skin was shaved, cleaned and abraded with alcohol prior to applying a disposable two snap Ag-AgCl electrode with a 2 cm inter-electrode distance (IED) (Noraxon Dual Electrode, *Scottsdale, Noraxon, Arizona, USA*). Electrodes were aligned with the predicted muscle fibre orientations according to De Foa el al. (1989) [6]. To accommodate the substantial amount of skin movement occurring in the L1 and L5 regions during large range of motion movements as were required for several experimental tasks, two-snap electrodes placed at L1 and L5 sites were cut in half and, with the participant flexed to approximately 50% of their range of motion, electrodes were applied with a 2 cm IED. A single snap electrode (Noraxon Single Electrode, *Scottsdale, Noraxon, Arizona, USA)* was positioned atop the seventh or eighth thoracic vertebrae, depending on which was more prominent – Figure 2. Skin characteristics, key anatomical landmarks and electrode placements were noted on a transparent sheet which was used to assist electrode placement on subsequent experimental days.

To facilitate movement capture, participants were instrumented with reflective markers (10 mm diameter - *Motion Analysis Corporation, Santa Rosa, California, USA)* positioned atop spinous processes at the level of the seventh cervical vertebra (C7), the first and twelfth thoracic vertebrae (T1 and T12, respectively), the first and fifth lumbar vertebrae (L1 and L5, respectively) and over the estimated centre of rotation for the left shoulder and hip.

EMG signals were pre-amplified (gain 500) at a distance of 6.5 cm from the recording site; wireless signals were transmitted to the central receiver (Noraxon TeleMyo 2400R, *Noraxon, Scottsdale, Arizona, USA).*Data were sampled at 1024 Hz, band-pass filtered (Butterworth 10 – 500 Hz), A/D converted using a 12 bit National Instruments A/D card, and monitored continuously throughout recording with EvaRT software (*Motion Analysis Corporation, Santa Rosa, California, USA)*.

Motion capture data was recorded using a system of ten infrared cameras (Eagle digital cameras, *Motion Analysis Corporation, Santa Rosa, California, USA)* collected in tandem with the EMG data using the EvaRT software.

2.5. Data processing

Following collection, EMG signals were offset corrected (removal of electrical noise bias), Butterworth filtered (30 Hz highpass filter to minimize contamination from heart rate [8]), and RMS converted (moving window, 100 ms). Normalization trials were then rest adjusted quadratically. All trials were inspected visually for data collection errors: no trials required removal from the data set. The mean RMS EMG amplitude was then taken across the middle 5 seconds of each normalization trial.

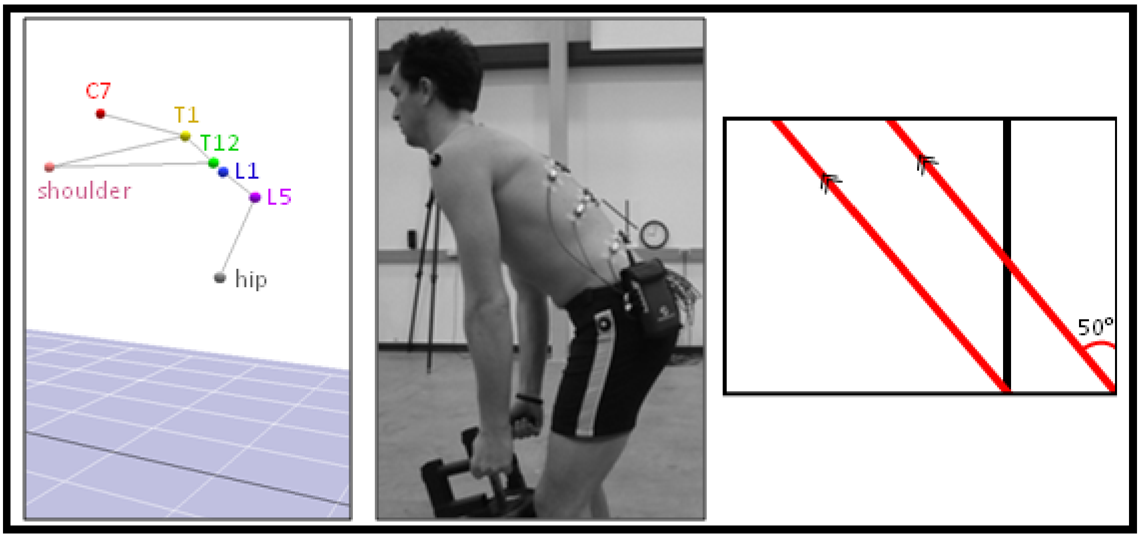

Fig. 1 – (*left*) Motion Capture template. *(centre)* Normalization task posture – 50°trunk flexion with 10 kg mass held in the hands, arms hanging vertically. Positioning aid used in EB-RVE trials shown on rear wall. *(right)* Schematic representation of positioning aid.

Sagittal plane trunk flexion angles were calculated as the angle between a vector from hip to shoulder marker and the vertical; the mean value across the middle 5 seconds of each normalization trial was then taken.

All data processing was done using custom software written for the study using MatLab (*Mathworks, Natick, Massachusetts, USA*).

For each subject and normalization task, pooled estimates of mean EMG amplitude and within-day variance were calculated across the three daily mean values for amplitude and variance. Pair-wise differences were evaluated between tasks for mean EMG amplitude using paired t-tests, and for mean variance using non-parametric Wilcoxon tests. Similarly, mean trunk flexion angles and within-day variances were calculated, and inter-task differences evaluated using a t-test and Wilcoxon tests, respectively.

3. Results

Mean EMG amplitude levels were significantly higher for M-RVE task trials than for EB-RVE trials for all channels ($p<0.03$), except the left T9 level ($p = 0.185$) – Table 1. In contrast, the mean lumbar flexion angle was not significantly different between tasks ($p = 0.198$): M-RVE 46.25°, M-EB 44.95°.

The magnitude of within-day variance for mean EMG amplitude was not significantly different between tasks for any channel, save the right side L5 recording site ($p=0.020$); right L5 variance during EB-RVE trials was approximately 75% as large as during M-RVE trials. A trend of higher variance was, however, observed across muscle activation signals measured during M-RVE trials compared to EB-RVE trials for all six channels.

Within-day variance for mean trunk flexion angle did reach significance between tasks: M-RVE trials showed significantly higher magnitudes of variance (8.69) than EB-RVE trials (4.34), $p=0.011$.

4. Discussion

A commonly reported sub-maximal, static normalization task was examined to determine the effect of the level of meticulousness in regards to trunk positioning on the mean amplitude and variance of lumbar erector spinae EMG. No statistical gains were shown as a result of meticulous positioning.

Table 1 - Mean EMG amplitude (mV) across trials for meticulous (M-RVE) and 'eye-balled' (EB-RVE) normalization tasks. Δ = difference between M-RVE and EB-RVE trials, with 95% confidence intervals (CI). P-values shown for paired t-tests; bolded p values indicate significant difference between M-RVE and EB-RVE amplitudes.

	site	M-RVE	EB-RVE	Δ	95% CI	p
right	T9	94.30	86.91	7.39	0.89 - 13.89	**.029**
	L1	93.59	85.66	7.94	1.63 - 14.25	**.017**
	L5	85.56	78.97	6.59	1.82 - 11.36	**.010**
left	T9	87.39	82.27	5.12	-2.75 - 12.99	.185
	L1	91.56	82.63	8.93	3.21 - 14.64	**.005**
	L5	93.11	85.11	8.00	2.75 - 13.24	**.006**

Mean EMG amplitudes differed between tasks, with the meticulous method resulting in significantly higher erector spinae muscle activation levels compared to the 'eye-balled' trials. While there was a trend for participants to maintain a slightly more flexed posture during M-RVE trials, the flexion angle was not significantly different: muscle activity differences cannot therefore be attributed to an increased demand, as would be expected at a higher trunk flexion angle to counteract the force of gravity on the mass of the trunk.

Previous studies examining precision control in trunk posture have not found significant increases in amplitude of individual or synergist muscle groups in response to increased precision demands [2,19]. In both these studies, visual information was provided both to modulate the precision demands of task and to provide feedback. Willigenburg et al. [19] concluded trunk precision control was regulated using feedback mechanisms given the absence of findings that would indicate a feedforward control mechanism, namely increased agonist and agonist muscle activity in response to increased precision demands.

In the current study, it is possible that participants perceived that an increased precision was asked of them during the meticulous task and may have consequently increased efforts to maintain 'exactly' the position in which they felt they had been meticulously positioned. This perception could have resulted from the increased efforts taken in positioning the participant and/or because the investigator who guided the participant into the desired flexion position remained seated beside the participant throughout the course of the trials (although no feedback was given to the participant from the investigator). It must be noted that the verbal instructions given to participants regarding what to do once in the desired position was attained did not differ between tasks, so any change in effort towards maintaining a specific posture was strictly self-imposed.

During all normalization trials, participants were instructed to maintain a neutral neck posture, and to stare straight ahead in this posture. Since the only things in front of the participant were a blank wall, located approximately 10 m away, and the bare floor between the participant and the wall, only very minimal visual feedback was available to the participant. As a result, proprioceptive feedback was likely the primary source of feedback on trunk position This is in contrast to the study by Willigenburg et al. who reported that, between proprioceptive and visual feedback sources, visual feedback was 'probably … the dominant source of feedback when precision demands were high' [19]. In the absence of strong visual feedback (for example, monitoring trunk flexion on a display screen with feedback provided on the targeted trunk angle), perhaps a feedforward strategy of postural control is employed rather than a feedback system to modulate trunk position demands, which would therefore involve increased muscle activity of the trunk musculature to increase trunk stiffness.

To corroborate this hypothesis one would expect to see increased muscle activity of both trunk flexors and extensors with increased precision demand. Abdominal EMG data is thus also required, but unfortunately such data is not presently available from this data set. Further examination into the effect of trunk postural control in the absence of visual feedback may prove in our understanding of postural control mechanisms. This information could also influence task selection for use in normalization or experimental tasks.

A higher amount of within-day (between trials) variance was found in trunk flexion angle for M-RVE trials as compared to EB-RVE trials: this finding was at odds with our hypothesis. If participants did self-impose an increased precision demand on their static trunk flexion angle, it would appear that the net effect of such efforts was opposite to that desired. This finding is also in opposition to that of Willigenburg et al. who reported decreased trunk angle standard deviations with increased precision demands. In regards to within-day variance in the EMG data, there was a trend for M-RVE trials to exhibit a higher degree of variance in muscle activation levels compared to EB-RVE trials, but this did not reach significance.

Taken together, it is possible that when more precise trunk postural control is desired, or required, with minimal visual feedback, increased muscle activity levels and increased postural variation will simultaneously occur; this could have serious implications for experiments investigating tightly regulated trunk flexion or bending angles.

When planning and conducting studies, one must consider the cost/benefit ratio not only from a statistical perspective, but also from a financial perspective. For the M-RVE task, two investigators were required: one sitting beside the participant who positioned and monitored the trunk posture (and who remained there throughout the trail), and one to run the data collection computer and monitor the quality of the data. For the EB-RVE task, only one investigator was required, as they could match the participant to the posture marked on the wall while also running the data collection computer and monitoring the collected data. Given the findings of the current study, it would not seem cost effective to follow the meticulous strategy for this particular normalization task. Care should, however, be taken in extrapolating these findings to other normalization tasks or postures; further study is required to examine the meticulousness issue in other tasks.

In this study extra time was also spent on a brief education and training of participants in the difference between hip and spinal flexion. While time is generally scarce in the field (and often also in the lab) for experimental set-up, it may prove worthwhile to spend one to two minutes demonstrating and having participants try hip versus spinal flexion, and then clearly specifying which movement should be used in the normalization task employed in the study. We did not specifically evaluate this question as all participants underwent training before the onset of the data collection.

A limitation of this study is that a particular trunk flexion angle can be achieved in myriad ways given the high number of degrees of freedom in the spine; this is true both for the intervertebral kinematics and the utilised muscle activation strategies. Further, trunk flexion can include both flexion about the hip and flexion at the level of the individual vertebrae. Participants in this study had been taught and had practiced the difference between hip and spinal flexion, and were instructed to try and achieve the positions using hip flexion. This may mean our data represent a best case scenario as compared to the repeatability another group of manual material handlers might demonstrate having not received postural training or specific instructions on which joint or region of the spine to use to achieve a flexed posture. Still, 50° trunk flexion exceeds the amount of hip flexion we expected most participants could achieve. Variability can therefore result due to altered flexion strategies and the corresponding selective activation of muscles surrounding each of the joints.

Another limitation of this study is that only sagittal plane (flexion/extension) postural data was considered. It is possible that lateral bending or rotation movements could account for some of the observed differences between the M-RVE and EB-RVE tasks. However, given (i) the normalization task was a simple flexion posture, (ii) participants had received training and practice in lumbar flexion and hip flexion movements in addition to practicing the specific normalization task, and (iii) participants were guided, to some degree, to the desired posture in both M-RVE and EB-RVE trails, we believe deviations in other planes were minimal.

Finally, this study has only considered the effect of meticulous trunk angle positioning during a single, sub-maximal normalization task. Further study is required before the findings can be generalized to other postures or tasks. Also, other tasks may prove to have even lower within-day variance and thus serve to further minimize induced error.

4.1. Conclusion

The purpose of this study was to identify experimentally and clinically relevant normalization task(s) and practices which minimize the amount of variance introduced to the normalized EMG signal while also being time-efficient. Mean amplitude and variance across repeated trials of a static, sub-maximal normalization task were calculated for trunk flexion angle and muscle activation level (6 channels of EMG) using two approaches for positioning participants for the task: a high degree of meticulousness with respect to trunk positioning, and a less rigid approach to trunk positioning, similar to what might be feasible in a field-based study. The less meticulous, less labour-intensive, more cost effective approach proved equal or even superior to the more meticulously collected task in terms of kinematic repeatability and within-day EMG variance. These findings are encouraging for field study applications where strict, meticulous methods are not feasible and may prove informative for laboratory studies using lumbar EMG.

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