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Ergonomic evaluation of task execution: Surface electromyography in muscular activity screening

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Abstract

Background and Purpose: *In this study surface electromyography (sEMG) was used as stand alone acquisition tool in order to emphasize possibilities of sEMG utilization as a screening tool for ergonomic purposes. We presented comparison for task completion variations based on processed sEMG data, where sEMG was used as muscular activity screening tool with the objective to offer decision in the most convenient task variation. In this context, muscular activity screening used in this paper was based primarily on muscular activity index and its transformations, where such data were correlated with electrical energy induced by activated muscle groups.*

Material and Methods: *Analysis of two different approaches to the fixed medical table and upper trunk alignment with table surface as the final target is performed for this purpose. Surface EMG signals were recorded using an eight-channel fiber optic TELEMG system (BTS S.p.a.) sampling at a frequency of 1000 Hz for selected muscles of right body side alone, in order to maximize muscular activity overview. If set otherwise (for both body sides), 8 available channel electrodes reduced the number of monitored muscle groups to 4 for each body side, causing decreased comparability and objectivity of muscular activity screening.*

Results and Conclusion: *Finally, after benchmarking task routines, Model 2 as routine approach was less demanding than Model 1, muscular activity index as equivalent to energy or work done over time in the monitored muscles was suitable for the purpose of muscular activity estimation, but should be expressed with consideration of muscular activity duration as muscle energy expenditure per time unit. Despite its imperfections, sEMG may be exploited as stand alone and as complement to other available acquisition and analysis tools.*

INTRODUCTION

Response of human body and its subsystems to everyday tasks and activities are important in ergonomics and other similar disciplines in order to investigate and understand human-system-environment bonds and interrelations. In the case of familiarity with these bonds, we are a step closer toward decreasing errors from ergonomic point of view, which is beneficial for all. One of the objectives of ergonomic analyses in human work and activity evaluation is to estimate the level of task demands and activity parameters in order to find the best effort-effect ratio, or to explore options for improving effectiveness. Such objective requires suitable evaluation procedure and standards for valuation of obtained results. This leads design of evaluation parameters, or sometimes more appropriate, evaluation coefficients required for this purpose.

In this study surface electromyography (sEMG) was used as a stand alone acquisition tool in order to emphasize possibilities of sEMG utilization as a screening tool for ergonomic purposes described above. If other acquisition systems are employed as well, sEMG may, as a complement tool, support advanced and complex ergonomic analyses. For the purpose of this paper, we present comparison of task completion variations based on processed sEMG data, where sEMG was used as a muscular activity screening tool, with the objective to offer decision in the most convenient task variation. The use of sEMG in order to determine muscular activity level as musculoskeletal response to work place conditions has been well elaborated and, in most cases, it is required to obtain MVC (maximal voluntary contraction) EMG signal for each monitored muscle *(1, 2, 3, 4, 5, 6, 7, 8, 9, 10)*. This is difficult to achieve correctly in many cases, which may impact the usefulness and speed of ergonomic analysis. In this context, muscular activity screening used in this paper was based primarily on muscular activity index and its transformations, where such data were correlated with electrical energy induced by activated muscle groups.

Muscular activity index MAI is defined as the entire area under the rectified EMG waveform, derived by definite integration over specific time interval. Calculation of the *MAI* involves removing of all negative phases of the raw EMG (full wave rectification), because in this way it retains all the energy of the signal *(1, 9, 10)*. The integral of the rectified EMG is then calculated over a specific time period *T*. The integrated EMG (reported in μVs or mVs) is mainly used to provide an estimate of the total amount of muscular activity during analyzed movements, and is calculated by by applying following expression:

$$MAI = \int_0^T |EMG(t)| dt$$

where: EMG(t) is the rectified EMG signal, and T is the time over which the *MAI* is calculated.

Therefore, muscular activity index is considered as appropriate, useful and comparable value, but also it may be useful to take into account the raw EMG data in order to overview muscular coordination and complexity of movements, if the movement of human body and its segments is involved, or analysis requires it. Objectivity of this analysis demands identical experimental setup for all analyzed task variations, exact and reliable data processing and, finally, appropriate comparison criteria.

METHODS AND MATERIALS

For the purpose of ergonomic evaluation where muscular activity index is exploited for decision making on the least demanding task completion, but also to accentuate such evaluation procedure for similar purposes, analysis is conducted for two different approach procedures (models) to the medical table, with identical objective. According to this objective women's upper trunk should face and level with the table surface, but the way it should be done is evidently different. Medical table used for the experiment was 0.75 m high, positioned as it is in the real circumstances. In order to clearly and objectively analyze EMG data together with estimation of real-time effort differences between models, especially from the aspect of effort- effect ratio, a single female subject was used for the experiment. Also, since this paper should emphasize options and parameters of sEMG use in ergonomic evaluation of task completion variances, the number of female subjects was considered less significant. Furthermore, in cases where it is important to evaluate task demands on individual basis (evaluating workplace demands, personal working abilities, most adequate person for a task, etc.), it may be important to quickly offer relevant results, which promote such approach. This approach is expected to offer true insight in differences between both approach models, without a risk of masking the obtained results and findings with some other significant parameters, which may occur if analysis engages more subjects. This takes into account possible impact of different anthropometrics, physical abilities, psycho-physical profile and shape, etc. However, a larger number of subjects could provide information of how subject size, age, abilities, etc would impact task completion efficiency and therefore may be used as the basic of workplace design and regulations of some of our future research objectives.

Models – approach procedures

Routine approach that consisted of climbing the table surface was named Model 1. After climbing the table, a female subject was supposed to lie down on the table surface for a short period of time (duration was irrelevant), and go back to starting position, which is presented in Figure 1 with its movement phases.

Model 2, to some extent simpler, was a routine approach in which the subject was expected to step forward to the table and flex the trunk above the table surface, aligning upper trunk to it. She remained in this position for a short period of time (duration irrelevant), and went back to starting position, which is presented in Figure 2 with its movement phases. Both models are considered as possible for a female subject to carry out, without the risk of muscular or other physical exertion.

EMG data acquisition

Surface EMG signals were recorded using an eight--channel fiber optic TELEMG system (BTS S.p.a.) sampling at a frequency of 1000 Hz. EMG activity was recorded through a pair of Ag/AgCl surface electrodes, prelubricated with electroconductive gel, and placed according to standard anatomical landmarks (following SENIAM protocol from 1999.) for selected muscles of the right body side alone in order to maximize muscular activity overview. If set otherwise (bilaterally), 8 available channel electrodes reduce the number of monitored

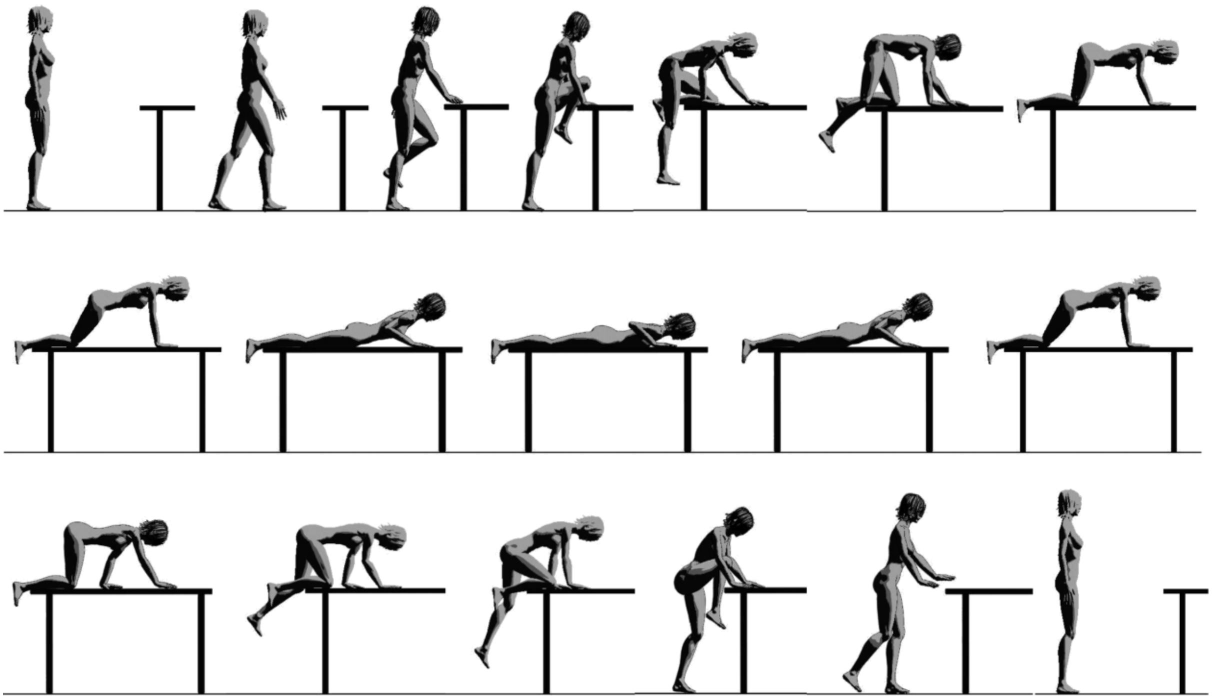

Figure 1. *Overview of Model 1 approach procedure phases.*

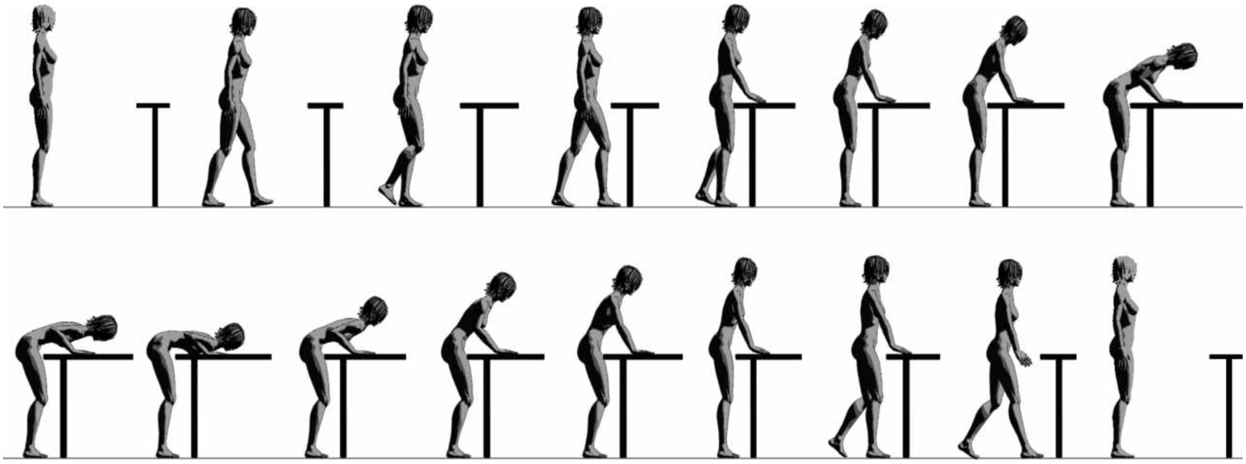

Figure 2. *Overview of Model 2 approach procedure phases.*

muscle groups to 4 for each body side, causing decreased comparability and objectivity of muscular activity screening. However, since only one body side is monitored while there are non symmetrical approach movements, it was decided that the monitored body side should be the dominant one, as usually more exerted and engaged. Furthermore, it should be taken into consideration that this setup may invoke unexpected result aspects which are the cause of necessity to create experiment setup for every analyzed event. Models 1 and 2 were set as a single experimental event in order to assure comparability. Muscle groups selected to be monitored for this experiment were therefore reduced to selection of those considered as the most engaged for both models, assuming that they are comparably and obviously active during both routines (models of task completions). Both approach procedures were performed continuously, with short rest, since fatigue shouldn't occur. Eight muscle groups which are considered as the most engaged and therefore significant, are listed below:

- channel 1 – m. biceps;
- channel 2 – m. triceps;
- channel 3 – m. latissimus dorsi;
- channel 4 – m. erector spinae;
- channel 5 – m. gluteus maximus;
- channel 6 – m. rectus femoris;
- channel 7 – m. biceps femoris;
- channel 8 – m. gastrocnemius,

which correspond to 8 channel telemetry system. Electrodes were positioned on the subject according to standard anatomical landmarks which should assure repetitiveness of acquired results. Once positioned, electrodes were on the subject until acquisition of sEMG data for both routines (Models 1 and 2) was completed. In this manner we assured that electrodes recorded comparable EMG data from identical positions. SEMG signal was obtained for both models from the start to finish position and back, simultaneously with video camera, in order to identify sEMG signal with movement. In order to acquire resting EMG level, before starting with using the approach models, we recorded EMG data in as much as possible relaxed standing position. In this manner it was possible to estimate the level of rectified resting EMG value. This value was recognized as different for every muscle group which was taken into account.

EMG activity index evaluation

Acquired raw surface EMG data for previously mentioned monitored muscles were processed off-line on a personal computer using dedicated software (Myolab; BTS S.p.a.), which allows obtaining valuable and desired results of muscular activity index level in real time, for selected models,. Even the raw EMG signal was considered important in order to compare approach models, but with cautiousness. Analysis of acquired electromyograms for each channel consisted of several steps: the zero offset full wave rectification of raw EMG data to translate bipolar signal to single polarity, resting value cut-off, and finally integration of refined EMG form, with resulting muscular activity index as the area under the curve of processed electromyograms *(9, 10)*. These procedures are not new, but the way the obtained results may be exploited in ergonomics and other human-system interactions are wide open, which we are going to discuss, applied on this experimental example.

RESULTS

Acquired surface EMG data were processed according to previously mentioned procedure, using well documented and described methods *(1, 2, 5, 11, 12, 13)*. We derived sEMG overall muscular activity index for all monitored muscle groups and for both Models, which is shown in Figure 3. It is possible to compare activity index for any monitored muscle group, between Models 1 and 2. Muscular activity indices presented offer visible differences for analysis, but this may be misleading since the duration of monitored activities in Models differs. Duration of monitored activities in Model 1 is 8.8 seconds, and in Model 2 6.4 seconds. Due by resting cut-off value of full-wave rectified EMG data for each EMG channel, the presented activity index is acceptable as real and total muscular activity indicator. It is somewhat expected that Model 1 represents higher musculoskeletal demands, but the data presented in Figure 3 is not correct enough to make direct comparison because of obvious duration difference. As presented, activity index graph expresses absolute values over activity duration, the impact of muscular activity duration may mask muscular activity intensity, so the duration of monitored subject activities should be considered. In order to achieve preferred objectivity, we calculated the average muscular activity index values for both Models, as shown in Figure 4. *Muscular activity index average MAIA* is de-

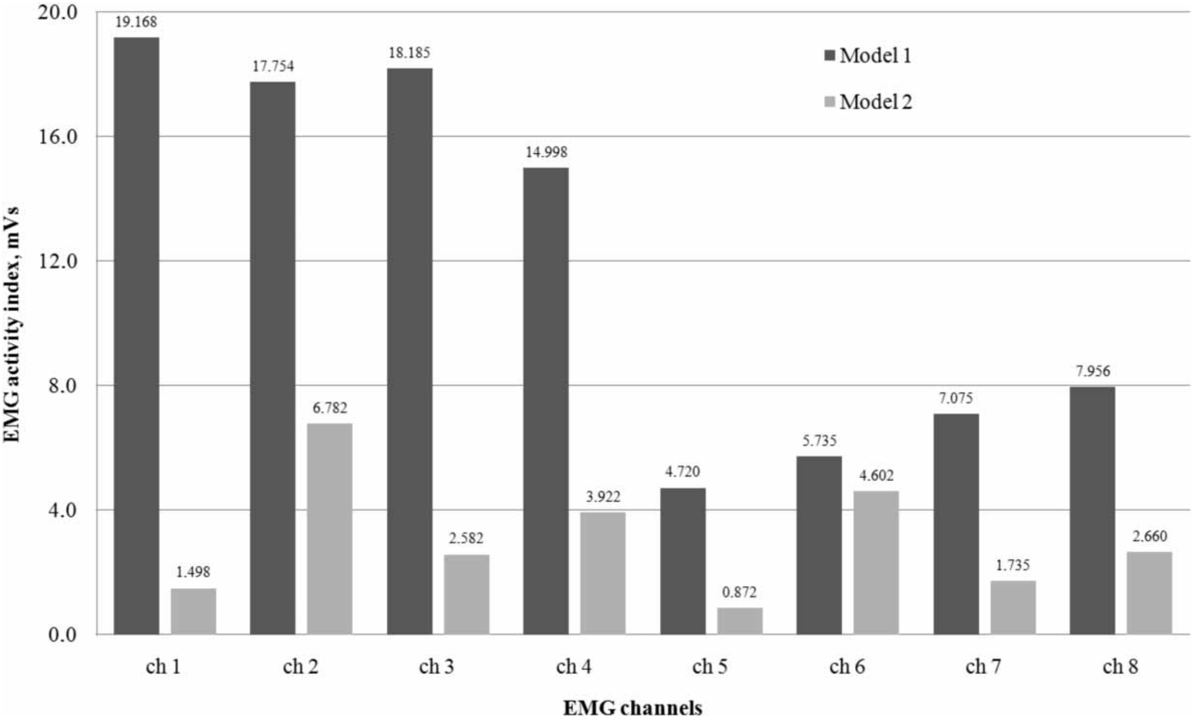

Figure 3. *EMG activity index (MAI) values for both Models in relation to EMG channel.*

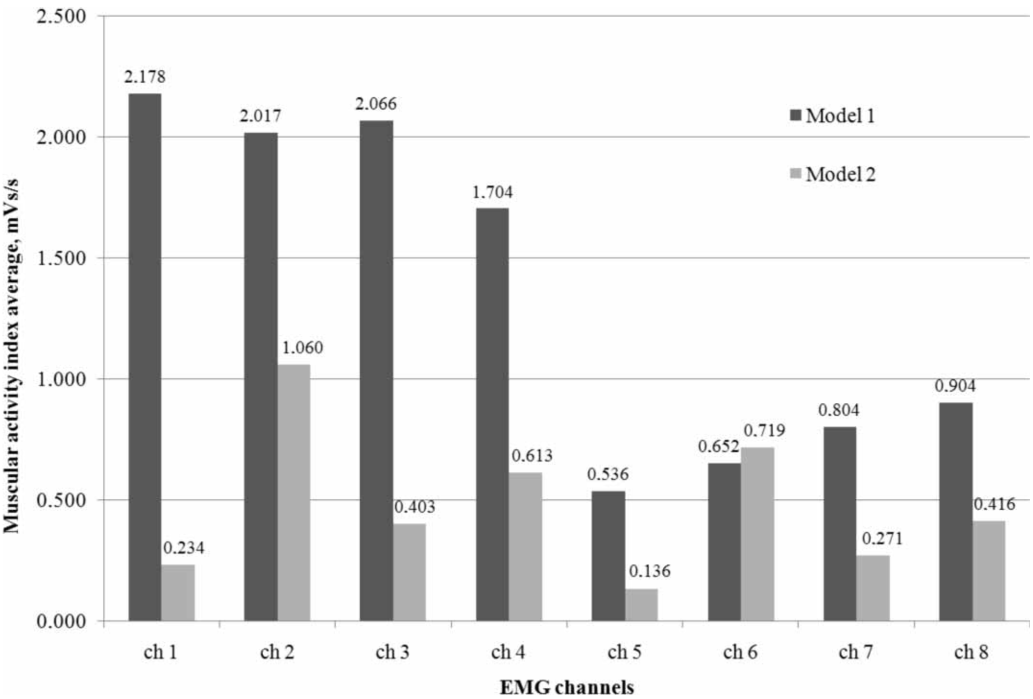

Figure 4. *Muscular activity index means (MAIA) for both Models in relation to EMG channel.*

fined as average value of muscular activity index (*MAI*) for specific time period *T*, and it has also been termed as Average Rectified EMG (*AREMG*), Average Rectified Value (*ARV*), Mean Absolute Value (*MAV*) and the Mean Amplitude Value (*MAV*) *(9, 10),* and is calculated according to the following expression:

$$MAIA = \frac{MAI}{T} = \frac{1}{T}\int_0^T |EMG(t)|dt$$

where the resulting integrated EMG (*MAI*) is finally divided by time period *T* to form the *MAIA* (reported in μVs/s or mVs/s). In this manner we prevented misinterpretation if lower muscular activity lasts long enough but, on the other hand, we use average values which may not represent real muscular activity intensity. Therefore, muscular activity index of analyzed channel may be derived for shorter time periods or intervals, especially if *MVC* (Maximal Voluntary Contraction) EMG data is available.

Just as notification, there was no noticeable physical exertion stated by subject, movements were comfortably performed, and there was no report by the subject that indicated more than moderate difference in muscle activation levels, except in few short time intervals.

DISCUSSION

Muscular activity screening procedure based on surface EMG applied on presented case in estimation of musculoskeletal system response to task completions highlighted several aspects and findings:

- analysis objective to extract less demanding task execution determined that screening of muscular activity should be completed as general estimation, where muscular energy expenditure is most appropriate;
- interpretation of presented results leads towards conclusion that Model 2 as routine approach is less demanding than Model 1, which is evident in Figures 3 and 4;
- muscular activity index as equivalent to energy or work done over time in monitored muscles is suitable for the purpose of muscular activity estimation, but should be expressed with consideration of muscular activity duration as muscle energy expenditure per time unit;
- average values of muscular activity indexes do not represent real intensity of muscular effort, so the applicability of this data must be revised: the full wave rectified and integrated EMG signal should be analyzed in appropriate time intervals with peak data consideration;
- objectivity of muscular activity screening is limited with the number of available EMG channels to collect data simultaneously, which may be increased if muscle groups of both body sides are monitored simultaneously. This requires a larger number of available EMG channels with effect in far better perspective of muscle activation, and therefore increased reliability;
- comparability of muscular effort estimation is possible for different activities even if there is no obvious similarity, in order to extract the less demanding one;

- muscular activity index and its transformations are applicable on a wide spectrum of ergonomic evaluations, not only to compare task completion routines, but also to initiate and guide their optimization, as well as to complement workplace design;
- despite its imperfections, surface electromyography as a standalone method as well as complement to other available acquisition and analysis tools, may be exploited.

Future investigations are needed in order to find new modalities and their confirmation to support sEMG as a standalone, completely reliable and useful ergonomic evaluation tool, potentially as a portable screening tool.

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