Upper Limb Repetitive Movement Risk Assessment by Means of sEMG Parameters

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Abstract. The aim of the study was to provide a biomechanical risk assessment in a mechanical engineering industry using sEMG fatigue parameters. Two experienced right-handed workers were enrolled for the study. sEMG signals were recorded bilaterally from the following upper limb muscles: middle Trapezius, anterior Deltoid, lateral Deltoid and long head of Biceps Brachii. The envelopes of the activity of each muscle were computed as a percentage of the Maximal Voluntary Contraction (%MVC). We also computed Root Mean Square (RMS) and Median Frequency (MDF) to investigate localized muscle fatigue. For the studied workstations, right muscles were more involved than left ones and consequently by means of JASA fatigue plot we observed more fatigue events in the right than in the left upper limb in both workers. Results showed different muscular behavior for each workstation and specific motor patterns. Despite the fact that the mean cycle activity failed to exceed 10% of MVC, activity peaks frequently reached up to 30% of MCV. These short-term peak values could be the cause of increased biomechanical risk. By studying sEMG fatigue parameters, it is possible to obtain a more detailed risk assessment and to provide insight towards workstation improvements.

Keywords: Joint analysis of the spectrum and amplitude · Localized muscle fatigue · Biomechanical risk assessment · MSDs

1 Introduction

The data presented last year by the President of INAIL (Italian Workers' Compensation Authority) to the Italian Parliament demonstrates that, in Italy, the reports of occupational illness caused by Musculoskeletal Disorders (MSDs) have increased continuously since 2011, in both absolute terms and percentage terms [1]. The most recent data shows that MSDs represent, with 37,240 reports in 2015, 63.2% of all occupational illnesses reported to the Institute. Similar MSDs values have also been reported in the United States [2] and in the European Union [3, 4].

Various methods for assessing the risk of the biomechanical overloading of upper limbs are proposed in the literature, also reported in the ISO 11228-3 standard [5]. Each of these methods assesses different risk factors but it is difficult for them to manage all

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the features of the many types of work that can be encountered in industrial environments. However, although in different ways, all of the methods do seem to agree on the fact that, of all the risk factors taken into consideration, that which most influences overall risk is the ‘strength’ factor, defined in the ISO 11228-3 standard as the “*physical effort of the operator required to execute the task*”.

With these methods, exertion is often quantified using scales of subjective perception, such as the Borg Scale [6], which presents many limitations.

In literature, several authors have tried to study the relationship between EMG and the Borg scale [7, 8] under isometric conditions, getting a certain degree of correlation.

There are also several studies that have already used Surface Electromyography (sEMG) to quantify muscular fatigue, under both static and dynamic conditions, in the laboratory and in the field [9–15].

The values that can be obtained in terms of average percentage of Maximum Voluntary Contraction (%MVC), within a typical mechanical engineering industry production cycle lasting between 40 and 60 s, are relatively low. Peak values within these production cycles are diluted as part of the mean %MVC and are not properly taken into consideration.

The aim of this study is to apply, in a real working situation, the Joint Analysis of the Spectrum and Amplitude (JASA) of sEMG [16–18], which analyzes the temporal changes in the amplitude of the sEMG signal, evaluated using the Root Mean Square (RMS) and the frequency of the sEMG signal, expressed as Median Frequency (MDF). By integrating the values of the angular coefficients of the regression lines of these two parameters, it is possible to obtain information regarding the physiological state of the muscle through division into four categories:

1) recovery (decrease in RMS and increase in MDF)
2) force decrease (decrease in RMS and decrease in MDF)
3) force increase (increase in RMS and increase in MDF)
4) fatigue (increase in RMS and decrease in MDF)

2 Materials and Methods

We evaluated two workstations (A and B) in a mechanical engineering industry that produces different pieces. We selected the line producing the heaviest one (weighing 5 kg). The two workstations differed in terms of the different contributions by the operator. In Workstation A, workers were less involved than in Workstation B due to an increased level of automation. Two skilled right-handed male workers were enrolled in the study. For each worker and for each workstation, we undertook data collection before the lunch break. Each data collection exercise involved the production of three pieces (three cycles); the job cycle was different for each of the three cycles since it was partially determined by the workers. However all the observed cycles were within the limit of 42 s, as suggested by the factory. Jammings occurred randomly during processing resulting in unscheduled breaks. However, during the data collection, there were no jammings in the production line or unusual worker activity. Neither of the participants had a history of trunk or upper limb musculoskeletal disorders and both were in very good health.

Bipolar sEMG was obtained during dynamic contractions with a sampling rate of 1000 Hz, using a 16-channel Wi-Fi transmission surface electromyograph (Free-EMG300 System, BTS, Milan, Italy). A pre-process filtering and denoising procedure was performed. After skin preparation, surface electromyographic signals were detected from each muscle by means of two Ag/AgCl pre-gelled disposable surface electrodes (H124SG, Kendall ARBO, Donau, Germany), which had a detection surface of 10 mm. Electrodes were placed in the direction of the muscle fibers, according to the Atlas of Muscle Innervation Zones recommendations [19].

We investigated bilaterally the following muscles of the upper limb: Middle Trapezius (TRAPsx, TRAPdx; left and right respectively), Deltoid Anterior (DAsx, DAdx; left and right respectively), Deltoid Lateral (DLsx, DLdx; left and right respectively) and Long Head of Biceps Brachii (BICsx, BICdx; left and right respectively).

For each muscle, muscle activity was computed as a percentage of maximal voluntary contraction (%MVC). In order to elicit the MVC from each muscle, six isometric exertions were performed according to SENIAM recommendations [20, 21]. Collected data was processed by means of Analyzer software (Smart Analyzer, BTS, Milan, Italy). The sEMG signals were rectified, integrated with a mobile window of 0.125 s, filtered with a 5 Hz Hamming low-pass filter and normalized to the maximum MVC value according to SENIAM recommendations; sEMG signals of MVC were computed using the same procedure.

The sEMG signals acquired were also processed by means of Analyzer software to compute the fatigue index. The lower and upper cut-off frequencies of the Hamming filter were 10 Hz and 400 Hz, respectively, and the common mode reaction ratio was 100 dB. Fatigue indices were calculated for each signal by dividing the signal into 500 ms epochs, within which amplitude and frequency parameters were computed. Since these parameters have demonstrated a linear trend [22], the linear regression was evaluated and then the data was normalized with respect to the y-axis.

3 Results

Whilst observed differences in muscular behavior, it was possible to identify, for each muscle, characteristic activity patterns, which were used to define the cycle start and end and to normalize the cycle durations.

Workstation A displayed significant activation values only for the right upper limb. A primary cluster of BICdx and DLdx activity, between 5% and 20% of the cycle, showed activation levels of about 15% of MVC for the BICdx and about 20% of MVC for the DLdx. Within the cycle, this initial stage presented the highest activation values. The BICdx and DLdx were also activated to a significant degree between 21% and 50% of the cycle and between 71% and 90% of the cycle. In both these stages, the level of activity was around 10% of MVC for the BICdx and 15% of MVC for the DLdx. The analyzed muscles of the left limb did not show significant overall levels of activation.

Workstation B also displayed a primary cluster of activity between 5% and 20% of the cycle. This involved, in particular, both Trapezia and the BICsx, with activity of about 15% of MVC, and the DAdx with activity of about 30% of MVC.

Between 20% and 50% of the cycle, activity was reduced in all the muscles under analysis.

A significant increase in activity was observed between 51% and 60% of the cycle. In this stage, for both the Trapezia and both the Anterior Deltoids, values of about 20% of MVC were observed, whilst the bicep activity was slightly higher (25% of MVC).

Another significant stage of activity involving all the muscles was observed between 65% and 75% of the cycle. Activation values in this stage were found to be 30% of MVC for the TRAPdx, DAdx and BICdx, 25% of MVC for the DAsx and 20% of MVC for the DLdx, DLsx, TRAPsx and BICsx.

Tables 1 and 2 display the results described above in relation to levels of activation expressed as %MVC.

Table 1. Summary, for each of the cycle stages identified for Workstation A, of the muscles most involved and respective level of activation expressed as %MVC.

Cycle time percentage and level of muscle activation (%MVC)				
5–20%	21–50%	51–70%	71–90%	91–100%
BICdx 15%	BICdx 10%	Negligible activity	BICdx 10%	Negligible activity
DLdx 20%	DLdx 15%		DLdx 15%	

Table 2. Summary, for each of the cycle stages identified for Workstation B, of the muscles most involved and respective level of activation expressed as %MVC.

Cycle time percentage and level of muscle activation (%MVC)				
5–20%	21–50%	51–60%	61–75%	76–100%
	Negligible activity		DAsx 25%	Negligible activity
		TRAPsx 20%	DLsx 20%	
TRAPsx 15%		DAsx 20%	TRAPsx 20%	
BICsx 15%		BICsx 25%	BICsx 20%	
TRAPdx 15%		TRAPdx 15%	TRAPdx 30%	
DAdx 30%		DAdx 20%	DAdx 30%	
		BICdx 25%	BICdx 30%	
			DLdx 20%	

Table 3. RMS and MDF regression coefficients and JASA interpretation for each muscle of the first operator and for the two investigated workstations (A and B)

Muscle	RMS A	MDF A	JASA A	RMS B	MDF B	JASA B
DAsx	0,0015	0	NC	–0,0007	–0,0005	force decr.
DLsx	–0,0013	–0,0008	force decr.	–0,0023	–0,0001	force decr.
BICsx	–0,0002	0,0008	recovery	–0,0002	0,0003	recovery
TRAPsx	0,0009	0,0011	force incr.	–0,0005	0,0003	recovery
DAdx	–0,0017	–0,0001	force decr.	0,0025	0,001	force incr.
DLdx	0,008	0,0003	force incr.	0,0053	–0,0008	fatigue
BICdx	–0,0011	–0,0013	force decr.	0,0055	–0,0019	fatigue
TRAPdx	–0,0015	0,0011	recovery	0,0022	–0,0004	fatigue

Table 4. RMS and MDF regression coefficients and JASA interpretation for each muscle of the second operator and for the two investigated workstations (A and B)

Muscle	RMS A	MDF A	JASA A	RMS B	MDF B	JASA B
DAsx	0,0006	0,0004	force incr.	–0,0005	0,0005	recovery
DLsx	–0,0011	–0,0001	force decr.	–0,0017	–0,001	force decr.
BICsx	0,0005	–0,0009	fatigue	–0,001	0,0008	recovery
TRAPsx	–0,0006	–0,0003	force decr.	–0,0001	0,0009	recovery
DAdx	0,0006	–0,0004	fatigue	–0,0031	0	NC
DLdx	0,0006	0,0002	force incr.	–0,002	–0,0009	force decr.
BICdx	0	–0,0004	NC	0,0024	–0,0011	fatigue
TRAPdx	0,0068	–0,0003	fatigue	0,0036	–0,0006	fatigue

Tables 3 and 4 below provide a summary of the angular coefficients of the linear regression obtained for the two parameters under investigation (RMS and MDF) and the respective JASA classification for the two operators investigated, for each of the eight muscles investigated.

Figures 1 and 2 below show JASA plots of the results of Tables 3 and 4. In Fig. 1 displays a Cartesian diagram of the distribution of events, for both operators and both workstations, for the left upper limb. Figure 2 shows the distribution of events, for both operators and both workstations, of the right upper limb.

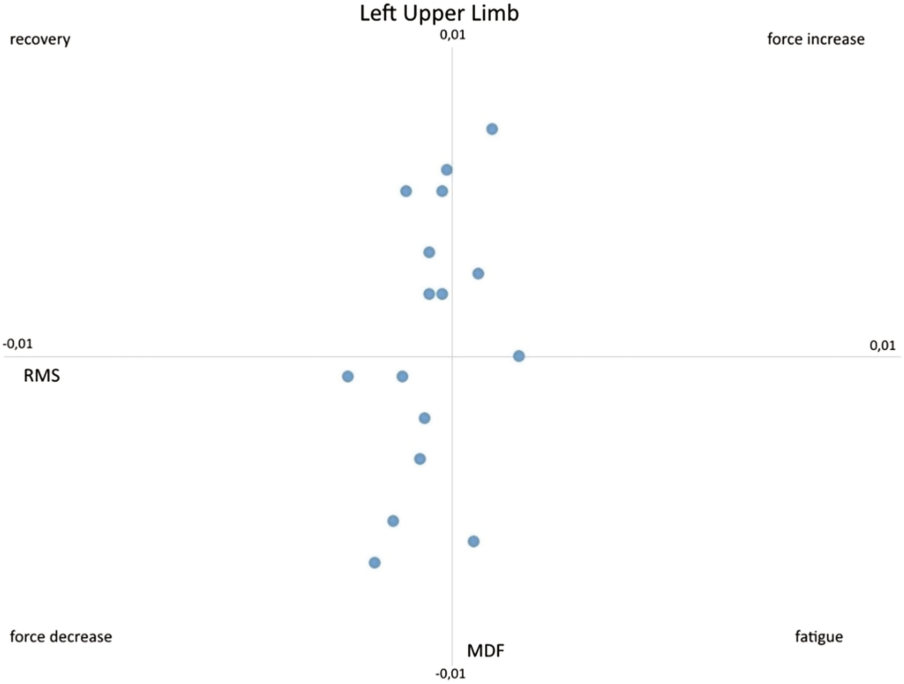

Fig. 1. JASA plot of the left upper limb muscles, for both operators and both workstations

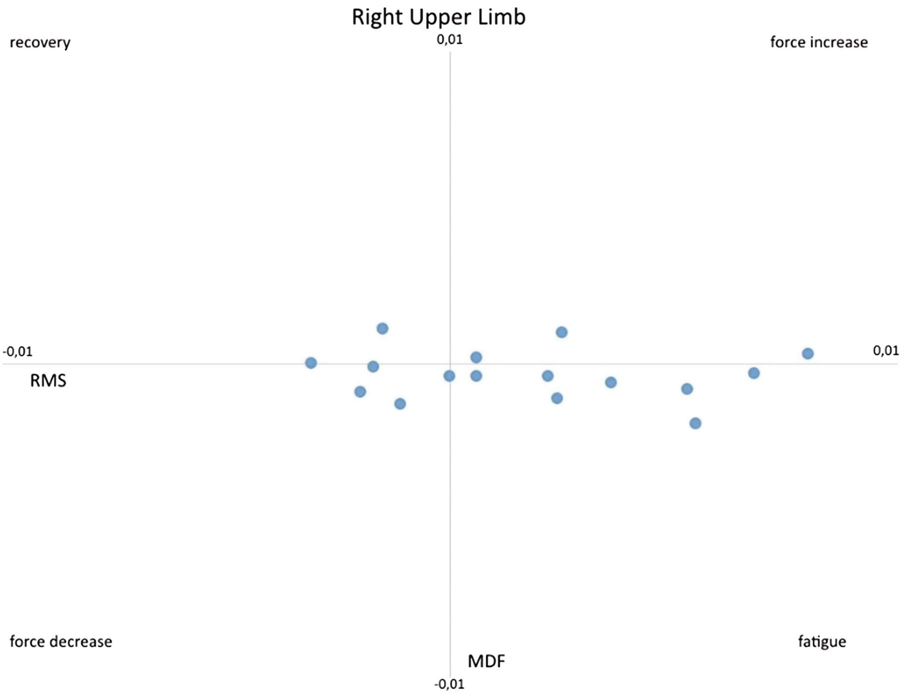

Fig. 2. JASA plot of the right upper limb muscles, for both operators and both workstations

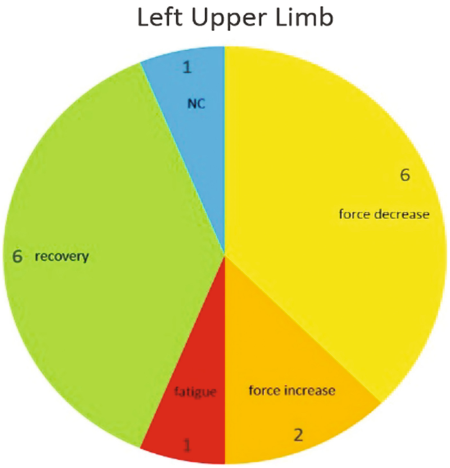

Fig. 3. Image showing the number of events for the left upper limb in the four JASA quadrants, for both workstations and both operators. Not Classifiable (NC) events are also represented

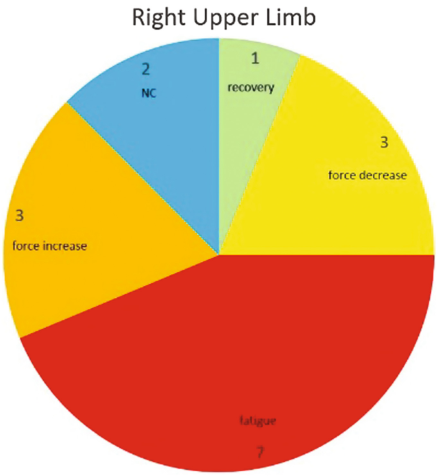

Fig. 4. Image showing the number of events for the right upper limb in the four JASA quadrants, for both workstations and both workers. Not Classifiable (NC) events are also represented

The pie charts of the figures, shown below, display the number of events observed in the four quadrants of the JASA plot for the left upper limb (Fig. 3) and the right upper limb (Fig. 4). Of the overall 32 events analyzed (16 per side), three could not be classified (NC) due to the angular coefficient of either the RMS (one event) or MDF (two events) being of zero value. With regard to the 16 events of the chart of the left upper limb, the greatest number of events was observed in the quadrants ‘recovery’ and ‘force decrease’ (6 in each). In addition, three events were observed in the ‘force increase’ quadrant and one in the ‘fatigue’ quadrant.

However, with regard to the 16 events on the right-hand side (Fig. 4), the quadrant with the greatest number of events was the ‘fatigue’ quadrant (seven events). In addition, three events were observed in the ‘force increase’ and ‘force decrease’ quadrant and only one in the ‘recovery’ quadrant.

4 Discussion

For each investigated muscle and for each workstation, characteristic motor activity was identified, making easy to identify start and end of the three cycles. The results demonstrate that, in the analysis of the two operators at the two workstations, the most involved muscles in Workstation A were the DLdx (15–20% of MVC) and the BICdx (10–15% of MVC). In Workstation B, however, all investigated muscles were involved on both sides. In particular, in Workstation B, there proved to be most use in the stage between 61% and 75% of the cycle of the TRAPdx (30% of MVC), DAdx (30% of MVC), BICdx (30% of MVC) and the DAsx (25% of MVC). This stage corresponds to the part of the work cycle that required the most effort, in which the operator had to remove the component being processed (weight 5 kg) from the container, at waist height, lift it to shoulder height and turn it over.

As far as concerns the results obtained from the JASA analysis, despite the fact that the data was collected under dynamic conditions and not under static conditions, as recommended by Merletti [23], a considerable number of events were observed in the ‘fatigue’ quadrant for the right upper limb, as illustrated in Fig. 4.

The results proved more conflicting for the left upper limb, however, which, especially for Workstation A, was used less and with much lower activation values.

It was not possible to carry out further, more representative data collection, due to the limited time we were awarded by the company to undertake our study.

The results we obtained demonstrate that sEMG proves to be, to date, a technology capable of providing useful indications for biomechanical risk assessment, including in actual work conditions and we can conclude that our results confirm that stated by Cirfrek [24] in his review: “*…the future of this methodology (sEMG) is projected by estimating those methods that have the greatest chance to be routinely used as reliable muscle fatigue measures…*”.

In any case, research on broader samples of the working population is necessary in order to verify the effectiveness of JASA under dynamic conditions within real manufacturing situations.

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