# Manifestations of muscle fatigue during repetitive low-moderate intensity work: a brief review

Joana Santos, Pedro Monteiro, Alberto Sérgio Miguel, Rubim Santos, J. Santos Baptista and Mário Vaz
FEUP

## Abstract

Muscle fatigue is a complex phenomenon that has been suggested to be an important precursor for work-related upper-limb musculoskeletal disorders. The assembly work is an example of low-moderate intensity work with elevated risk of muscle fatigue development. This review was performed to summarise and analyse the studies that investigated the influence of work requirements on muscle fatigue development in workplaces or experimental setting. This review was based on relevant articles published from 2000 to 2013 in the research platform Web of Knowledge. The studies included in this review were performed in humans and assess peripheral muscle fatigue in upper limbs during occupational activities. The search yielded 103 articles and 10 were included, according to inclusion criteria. Few studies were conducted in real work environment and the most common methods used to assess muscle fatigue were surface electromyography (EMG). The work duration and intensity level were the determinants of muscle fatigue that had more consistent results in terms of EMG- based parameters. In the studies that report subjective measurement of muscle fatigue, the subjective ratings increase. More research is needed to understand the impact of work requirements on muscle fatigue and work-related performance.

**Keywords:** muscle fatigue, assembly work, repetitive work, low-intensity work, upper limbs.

## 1. INTRODUCTION

The state of "fatigue" is multidimensional and more research is needed to better understand this phenomenon. In general, authors divide "fatigue" into physical and mental dimensions. Bush (2010) described three categories of "fatigue" in the industrial environment: muscular fatigue, mental fatigue and shift work related fatigue. Fatigue affects health, well-being, increases work accidents and reduces performance.

The reduction of muscle functional capacity is generally referred to as muscle fatigue (Fuller et al., 2009). Several authors (De Luca, 1984; Big-land-Ritchie et al. 1986; Vøllestad et al. 1997; Blangsted et al. 2005) report that muscle fatigue is characterised by a reversible state and an exercise-induced reduction in the maximal capacity to generate force or power output. Muscle fatigue is a complex phenomenon that can occur as a result of alterations at the central nervous systems, neuromuscular junction (central fatigue) or the muscle fiber (peripheral fatigue) (Williams and Ratel, 2009).

In industrial environment it is essential to reduce the occurrence of muscle fatigue, since it has a great impact on task performance. However, the exposure to environmental factors (like vibration, temperature extremes) and task-related risk factors, including static posture, repetitive and forceful movements in the workplaces, increase the risk of muscle fatigue. Some studies have shown that fatigue is a risk factor for musculoskeletal injury (Ding et al., 2000; Nussbaum et al., 2001; Lomond and Côté 2010).

The work in assembly lines is characterised by monotonous and repetitive low-moderate force tasks. According to Eurofound (2010) more than 60% of workers currently report to perform repetitive hand or arm movements at work. Numerous studies have suggested that muscle fatigue may develop during repetitive work and it is influenced by work requirements, such as work pace, intensity of task, duration of task and other determinants. However, the studies related to fatigue at work have not yet produced consistent evidence about the relationship between work patterns, task demands and worker performance during low-moderate intensity repetitive tasks, in order to allow the development or improvement of existing guidelines for this type of work (Australian Safety and Compensation Council, 2006).

This review aimed to analyse the studies that have investigated the influence of work requirements on the muscle fatigue development in workplaces or experimental setting.

## 2. MATERIALS AND METHOD

### *Search strategy*

Relevant research studies were sourced using the research platform named Web of Knowledge refined to specific databases as Web of Science and Medline (2000 - October 2013). A search strategy was developed using the terms "muscle fatigue", "upper limbs", "assembly work", "repetitive work" and "low-intensity work" (or synonyms as "low-force work").

### *Study selection*

The references were first screened based on the title and then on the abstract. Eligible articles were (1) published in peer-review journals in the English language (2) those that considers the development of peripheral muscle fatigue in upper limbs during repetitive low-moderate intensity work (3) those that investigated the relationship between work requirements (such as work pace, intensity of work, work duration, type of task, posture) and muscle fatigue and (4) those that assess muscle fatigue in occupational activities performed in realist work conditions and simulated in the laboratory.

## 3. RESULTS AND DISCUSSION

The search strategy yielded a total of 103 citations. A total of 43 were deemed potentially relevant based on title and/or abstract screening. A total of 10 studies were considered for the final analysis. Table 1 displays the flowchart of the search strategy.

Table 1: Overview of results.

| *Reference* | *Determinants of fatigue* | *Task* | *Main outcomes* |
|---|---|---|---|
| Horton et al., 2012 | Rotation frequency and task order. | Repetitive static shoulder abduction tasks; two exertion levels (15% MVC[1]; 30% MVC) for 1 hour either with or without rotation. | Rotation frequency and task order reduced fatigue and improved performance at higher exertion level. |
| Gooyers, and Stevenson, 2012 | Work rate. | Simulated Speed Fastening (SF) task - using a pneumatic, powered, pistol-grip hand tool - 7, 14 and 21 fasteners per minute (work rate) – 120 min | With the increase of work rate:<br>No significant changes in the 50th percentile upper extremity joint posture.<br>Increased in the muscle activity. |
| Bosch et al., 2012 | Temporal strategy - waiting time at the high (W1) and low target (W2) in seconds.<br>Performance, expressed in terms of timing error. | 1 hour repetitive arm reaching task (six 7-min work blocks) | During 1 hour:<br>Increased perceived fatigue<br>Increased EMG amplitude<br>Decreased EMG median power frequencies (MPF)<br>Increased EMG amplitude cycle-to-cycle variability<br>Changes in temporal movement strategy.<br>Increased timing errors. |
| Bosch et al., 2011 | Work pace. | 2 hours of repetitive pick and place actions so as to simulate industrial assembly at two work paces – "low work pace" (cycle time of 48s) and "high work pace" (cycle time of 38s) | "Low work pace" vs "high work pace":<br>No significant differences for the average EMG activity levels<br>No significant differences for the distance covered by the shoulder.<br>Increased perceived fatigue across time |
| Kimura et al., 2007 | Work duration | Simulated typewriting task for four 25-min sessions | During four 25-min sessions:<br>Increased perceived fatigue<br>Decreased average median frequency (MDF or MF) value<br>Increased root mean square (RMS)<br>Decreased muscle fiber conduction velocity (MFCV)<br>The EMG parameters did not recover completely during recovery period |
| Dai et al., 2007 | Frequency, weight and angle loads during 8 different tasks. | Eight wrist extensions in different frequency, weight and angle loads | The MPF and MF were significantly lower at high frequency load level than at low load level.<br>The fatigue of muscles varied in the same task. |
| Bosch et al., 2007 | Temporal aspects of task design. | Case study 1<br>Assembly of catheters by picking and placing small parts<br>Case study 2<br>Assembly task (a) Picking the product (b) visual control (c) placing the product. | Case study 1<br>Increased EMG amplitude<br>No significant temporal changes in the MPF<br>Case study 2<br>Increased EMG amplitude<br>Significant temporal change in the MPF<br>No clear relationship between the subjective and objective indicators of muscle fatigue |
| Garg et al., 2006 | Weight of workpieces, weight of hand-tools, shoulder postures, arm up time and arm down time. | Automotive assembly operations – 4 different tasks in a 1-min job-cycle, repeated 50 times | At the end of 50 min.:<br>Increased perceived fatigue / Decrease in the MPFs<br>No relationship between the MPF and job physical demands<br>Increased RMS values |
| Hostens and Ramon, 2005 | Work duration. | Car driving – 1 hour | After a 1 h drive:<br>Decreased of the MF<br>Decreased EMG amplitude<br>Decreased RMS |
| Emam et al., 2001 | Ergonomic aspects of task performance - different handle (conventional finger loop, rocker, and ball handle prototype). | Laparoscopic surgery | Subjective ratings - rocker and ball handles more comfortable.<br>Motion analysis – rocker and ball handles reduce angular velocity of elbow and shoulder joint<br>Muscle work - Significant muscle fatigue with finger loop instruments. |

[1]Maximum voluntary contraction (MVC)

A good task design can prevent workers discomfort and promote a more efficient and safe work environment. However, it is quite challenging to assess muscle force/power during the majority of work conditions, due the acyclic nature of the activities (Williams and Ratel, 2009; Soo et al., 2012) and also due to the constraints associated with the production goals. This review demonstrated that few researches have studied the manifestation of muscle fatigue in realistic working conditions. Only two studies were carried out in real conditions, while the others were simulated in the laboratory with small samples. The surface EMG technique was the most common method to assess muscle fatigue in repetitive low-moderate intensity work. In general, EMG manifestations of muscle fatigue is associated to a decrease in EMG power frequency and an increased EMG amplitude. In all studies that evaluated subjective signs of muscle fatigue, an increase was observed. However, no clear relationship between objective and subjective signs of fatigue was found. The subjective scales were often more sensitive than objective measures. The duration of tasks (work time) and intensity level were the determinants of muscle fatigue development that had more consistent results in terms of EMG- based parameters.

## 4. CONCLUSIONS

The influence of work requirements on muscle fatigue and performance are not completely understood. More research is necessary to know the temporal pattern of fatigue development and the relationship with upper limb musculoskeletal disorders and performance. Furthermore, it is necessary to improve strategies and kinetic and kinematic instrumentation to measure muscle fatigue in real work conditions.

To prevent work-related upper-limb musculoskeletal disorders, companies should know the physical characteristics of their workers and should quantify muscular force and fatigue during work tasks. These evaluations are important to design ergonomic work stations, to plan appropriate work-rest patterns and to prevent/assess the progress of disorders

## 5. REFERENCES


Australian Safety and Compensation Council. (2006). Work-Related Fatigue: Summary of Recent Indicative Research. Department of Employment and Workplace Relations (Ed.). Retrieved from http://www.safeworkaustralia.gov.au/sites/SWA/about/Publications/Documents/420/WorkRelated_Fatigue_Indicative_Research_2006.pdf

Biglandritchie, B., Furbush, F., & Woods, J. J. (1986). Fatigue of Intermittent Submaximal Voluntary Contractions - Central and Peripheral Factors. *Journal of Applied Physiology, 61*(2), 421-429.

Blangsted, A. K., Sjogaard, G., Madeleine, P., Olsen, H. B., & Sogaard, K. (2005). Voluntary low-force contraction elicits prolonged low-frequency fatigue and changes in surface electromyography and mechanomyography. *Journal of Electromyography and Kinesiology, 15*(2), 138-148.

Bosch, T., De Looze, M. P., & Van Dieen, J. H. (2007). Development of fatigue and discomfort in the upper trapezius muscle during light manual work. *Ergonomics, 50*(2), 161-177.

Bosch, T., Mathiassen, S. E., Visser, B., de Looze, M. P., & van Dieen, J. H. (2011). The effect of work pace on workload, motor variability and fatigue during simulated light assembly work. *Ergonomics, 54*(2), 154-168.

Bosch, T., Mathiassen, S. E., Hallman, D., de Looze, M. P., Lyskov, E., Visser, B., & van Dieen, J. H. (2012). Temporal strategy and performance during a fatiguing short-cycle repetitive task. *Ergonomics, 55*(8), 863-873.

Dai, W., Zhao, X., Wang, Z., & Yang, L. (2007). Electromyographical study on muscle fatigue in repetitive forearm tasks. *Journal of Huazhong University of Science and Technology-Medical Sciences, 27*(4), 358-361.

De Luca, C. J. (1984). Myoelectrical Manifestations of Localized Muscular Fatigue in Humans. *Crc Critical Reviews in Biomedical Engineering, 11*(4), 251-279.

Ding, J., Wexler, A. S., & Binder-Macleod, S. A. (2000). A predictive model of fatigue in human skeletal muscles. *Journal of Applied Physiology, 89*(4), 1322-1332.

Emam, T. A., Frank, T. G., Hanna, G. B., & Cuschieri, A. (2001). Influence of handle design on the surgeon's upper limb movements, muscle recruitment, and fatigue during endoscopic suturing. *Surgical Endoscopy and Other Interventional Techniques, 15*(7), 667-672.

Eurofound. (2010). Changes over time – First findings from the fifth European Working Conditions Survey. Dublin.

Garg, A., Hegmann, K., & Kapellusch, J. (2006). Short-cycle overhead work and shoulder girdle muscle fatigue. *International Journal of Industrial Ergonomics, 36*(6), 581-597.

Gooyers, C. E., & Stevenson, J. M. (2012). The impact of an increase in work rate on task demands for a simulated industrial hand tool assembly task. *International Journal of Industrial Ergonomics, 42*(1), 80-89.

Horton, L. M., Nussbaum, M. A., & Agnew, M. J. (2012). Effects of rotation frequency and task order on localised muscle fatigue and performance during repetitive static shoulder exertions. *Ergonomics, 55*(10), 1205-1217.

Hostens, I., & Ramon, H. (2005). Assessment of muscle fatigue in low level monotonous task performance during car driving. *Journal of Electromyography and Kinesiology, 15*(3), 266-274.

Kimura, M., Sato, H., Ochi, M., Hosoya, S., & Sadoyama, T. (2007). Electromyogram and perceived fatigue changes in the trapezius muscle during typewriting and recovery. *European Journal of Applied Physiology, 100*(1), 89-96.

Lomond, K. V., & Cote, J. N. (2010). Movement timing and reach to reach variability during a repetitive reaching task in persons with chronic neck/shoulder pain and healthy subjects. *Experimental Brain Research, 206*(3), 271-282.

Nussbaum, M. A., Clark, L. L., Lanza, M. A., & Rice, K. M. (2001). Fatigue and endurance limits during intermittent overhead work. *Aihaj, 62*(4), 446-456.

Soo, Y., Sugi, M., Yokoi, H., Arai, T., Kato, R., & Ota, J. (2012). Quantitative estimation of muscle fatigue on cyclic handgrip tasks. *International Journal of Industrial Ergonomics, 42*(1), 103-112.

Vollestad, N. K. (1997). Measurement of human muscle fatigue. *Journal of Neuroscience Methods, 74*(2), 219-227.

Williams, C., Ratel, S. (2009). *Human Muscle Fatigue* (1st ed.). New York: Routledge.