

ELECTROMYOGRAPHY AS AN OBJECTIVE MEASUREMENT FOR EVALUATING PHYSICAL FATIGUE: AN OVERVIEW

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Abstract

Nowadays, the detection of human fatigue is a major concern in society, industry, road safety and transportation research, due to its effect on human performance while performing tasks. The two main objectives of this review are to extract and understand better the electromyography (EMG) procedure and to identify any pertinent issues related to EMG assessment. Eleven relevant studies were presented in this review paper, chosen from several electronic databases. This review paper describes the study design of EMG, its analysis and findings. This review has provided an insight of EMG assessment for future study, particularly on the arrangement of the study design including the muscle part and setting procedure.

Keywords: EMG, fatigue, human, worker, driver

Abstrak

Pengesanan kelesuan manusia adalah suatu kebimbangan utama pada penyelidikan masyarakat, industri, pengangkutan dan keselamatan jalanraya pada masa kini. Ini disebabkan oleh kesannya kepada prestasi manusia ketika melakukan tugas. Dua objektif utama kajian ini ialah untuk memahami prosedur EMG dan mengenalpasti sebarang isu berkaitan penilaian EMG. Sebelas kajian yang dipilih daripada data elektronik telah dibentangkan dalam kertas kerja ini. Kajian ini menerangkan rekabentuk kajian EMG, analisis dan keputusan. Kajian ini dapat memberi gambaran tentang penilaian EMG untuk kajian di masa hadapan, terutamanya dalam penyusunan rekabentuk kajian termasuk bahagian sendi dan prosedur.

Kata kunci: EMG, lesu, manusia, pekerja, pemandu

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1.0 INTRODUCTION

In many occupations (eg: plantation, manufacturing) and leisure activities (eg: driving, sport), there are many tasks that involve repetitive movements. As a result, it can develop muscle fatigue and bring a negative effect to human performance [1]. In the field of biomechanics, fatigue can be defined as a decrease in physical movement performance due to internal and external forces [2]. One of the assessment methods to evaluate muscle fatigue is electromyography (EMG).

EMG is a technique for evaluating and recording the electrical activity produced by skeletal muscles. Actually, it is an electrical signal that has been stored at the muscle level [3]. González-Izal, *et al.* [4] had

summarized many different types of surface EMG models to assess muscle fatigue which is either isometric or static contraction, dynamic for non-stationary, as well as dynamic for time frequency, amplitude-based parameters, and spectral parameters. Results show that the isometric is easy to record due to static contraction. Meanwhile, the dynamic model is relevant to daily tasks. Nevertheless, it is difficult to interpret the signal and it is a very complex technique due to the non-stationary characteristics [4].

According to Atieh *et al.* [3] the EMG signal is easier to estimate than other signals such as nerves and brains. Therefore, this measure will be very useful to evaluate human physical fatigue in daily life. This study will present a brief review regarding EMG in

past studies in the contexts of sport activity, driver, motorcyclist and worker.

2.0 METHODOLOGY

A list of English language articles dated as far back as 2003 was compiled from Science Direct and Google Scholar websites. EMG, human fatigue, discomfort, worker, and driver were the keyword search terms for this paper. In addition, a secondary search was performed by using bibliography of retrieved articles in order to support the first retrieved paper.

3.0 RESULTS AND DISCUSSION

Table 1 shows a summary of EMG evaluation studies from eleven past studies in terms of their study design, analysis, and results. Based on Table 1, the majority of reviewed studies were conducted among car drivers.

3.1 Car Driver as Main Focus

It is believed that driving fatigue is one of the main reasons behind fatal crashes and injuries [5, 6]. It is due to the fact that driving a car requires substantial cognitive effort and attention from the brain. Therefore, the majority of the past studies had focused on car drivers to study fatigue. For example, Hostens & Ramon [7] had found that there is an increase in the amplitude and a decrease of the mean frequency in monotonous task performance with low level activity during car driving when using EMG.

3.2 Other Focus Groups in the Past Studies

Instead of focusing on the drivers, other studies were performed among motorcyclists and persons who perform daily activities. For example, Balasubramanian & Jagannath [8] had investigated the fatigue level among motorcyclists due to their riding activity by means of EMG, seat interface pressure, heart rate (HR) and blood pressure (BP).

In addition, they also used a self-rated questionnaire using the five points scale to identify the overall discomfort levels on their body parts such as the neck, shoulders, arms, hands, back, buttock and legs. The self-rated questionnaire was given after the end of the riding session. For the EMG, extensor carpi radialis (ECR), biceps brachial (BB), trapezius medial (TM), sternocleidomastoid (S), latissimusdorsi medial (LDM), and erector spine (ES) were evaluated bilaterally. Meanwhile, the pressure map was placed on the motorcycle to obtain the seat interface pressure reading. For the HR and BP, it was measured before and after the motorcycle riding. Findings indicate that the motorcyclists experienced fatigue potentially due to constrained riding posture. In

addition, it shows that the motorcyclist produces dominant pressure distribution with peak pressure at the ischium region. In terms of their HR and BP reading, HR was significantly increased between before and after riding. On the other hand, BP decreased due to the prolonged lower body immobilization, which causes poor circulation.

3.3 Application of Driving Simulator in EMG Studies

Numerous studies were performed in identifying physical fatigue by using EMG. Four past studies using the simulator were reported in this paper. A driving simulator was used to gain reliable information on drivers' behaviour and it is easy to control [9-12]. Methods and findings of the past studies were explained in Table 1. Even though some studies had used a simulator as part of the apparatus in the experiment, there were many assessments that had been conducted by researchers in the past studies. Some studies prefer to combine several methods to gain some robust and reliable findings.

For example, Jagannath & Balasubramanian [13] evaluated driver fatigue by means of EMG, electroencephalography (EEG), seat interface pressure, BP, HR, and oxygen saturation level using 20 subjects. Based on this study, it can be concluded that fatigue is increased with the increase of the test duration. Meanwhile, some researchers choose to observe human fatigue by using one to two methods and apparatus. It is because they have specific focus of body parts to take into account when it comes to making conclusion. Arora & Grenier [14], for example, investigated the trunk muscle by using EMG. In this study, 10 subjects were driving a simulator and they were required to control the steering wheel and pedals for gas and braking. All these setups were required to simulate driving posture during the exposure sessions. The findings show that EMG latency increased more in the vibration condition than in sitting without the vibration. In addition, there is a possibility to recover from acute effects of the whole body vibration with sufficient rest.

Table 1 Summary of recent human fatigue evaluation studies

No	References / study design	Objective EMG analysis	Other measures	Findings
1	Fuller <i>et al.</i> [15] Subject: 13 subjects Condition: L, NR (duration)	Part: 25mm medial to the midpoint between the C7 vertebra and the angle of acromion Setting: EMG was acquired using a TeleMyo EMG measurement system with an operating bandwidth of 10–350 Hz. EMG data were acquired from the descending Trapezius. At acquisition, all EMG signals were filtered using a dual-pass, fourth-order Butterworth filter, with a band-pass of 20–500 Hz. EMGs were then digitally converted using a 16 bit A/D board over a ± 10 V range, sampled at 1080 Hz, and stored for further analysis.	MVC for dominant shoulder elevation	During repetitive reaching, fatigue and postural perturbation compensations are organized so as to minimize the interaction with each other and to preserve the global task characteristics of the endpoint motion.
2	Arora & Grenier [14] Subject: 10 drivers Condition: S, 45 minutes	Part: RA, ES, EO Setting: Surface EMG electrodes were placed on the skin, 2.5 cm apart. Electrodes were placed according to Granata <i>et al.</i> [16] for the RA (3 cm lateral and 2 cm superior to the umbilicus); EO (10 cm lateral to the umbilicus with an orientation of 45 degree to vertical); and ES (4 cm lateral to the L3 and T9 spinous process).	-	EMG latency was increased more in the vibration condition than in sitting without vibration. Significant effects with respect to directionality were observed in the ES muscles. The EMG latency was reduced from the effect of perturbation after a 20 s rest period. Even though the EMG latency did not fully return to its Pre-test state, the present results still show that recovery from the acute effects of WBV is possible with a rest period.
3	Dong <i>et al.</i> [2] Subject: 17 subjects Condition: A, 1 minute	Parts: BB, AD and TB Setting: The EMG sensor used is a DelsysTrigno wireless sensor (37 mm \times 26 mm \times 15 mm, 16-bit resolution, 2,000 Hz sampling rate), which consists of a parallel-bar-based EMG measurement device and a triaxial accelerometer. The accelerometer is used to capture dynamic movements and impact simultaneously with the EMG data measurements	Survey of fatigue experiment	Mean frequency decreases with the increase of the fatigue intensity. According to previous work, we assume that the decrease of the mean frequency satisfies a linear relation with the working time of a muscle under fatigue.
4	Jagannath & Balasubramanian [13] Subject: 20 drivers Country: India Condition: S, 60 minutes	Parts: extensor carpi radialis (ECR), BB, MD, TM, S, LDM and ES Setting: EMG signals were acquired using 16 channel EMG machine (Wireless Myomonitor IV, Delsys Inc., Boston, MA) at a sampling rate of 1000 Hz. Raw EMG signals were filtered using 20-450 Hz band pas filter and 47-51 Hz band stop filter.	EEG, seat interface pressure, heart rate, blood pressure, and oxygen saturation level, Body Part Discomfort (BPD)	Results from EMG showed significant physical fatigue ($r < 0.05$) in back and shoulder muscle groups.
5	Balasubramanian & Jagannath [8] Subject: 20 male Condition: A, 60 minutes of motorcycle riding in a low traffic density environment.	Part: ECR, BB, TM, S, LDM and ES Setting: EMG signals were performed at a sampling rate of 1000 Hz. The raw EMG signals were filtered using 20–450 Hz band pass filter and 47–51 Hz band stop filter.	Seat interface pressure, heart rate, blood pressure analysis	Results showed that participants have significant ($p < 0.05$) physical fatigue in TM, LD and ES muscle groups during 60 min of motorcycle riding. Results suggest that the impact on local physical fatigue and seat discomfort is probably due to the static seating demand and prolonged sitting posture balance required to ride the motorcycle for an hour.

6	El Falou <i>et al.</i> [17] Subject: 11 drivers Condition: L, 150 minutes	Parts: From cervical ES and EO muscles Setting: EMG signals were performed using an Electronic Mazet located less than 10cm from the electrodes. The pre-amplification had an input impedance of 10G Ω , a gain of 600 at 100Hz, a band-pass of 20– 2000Hz, and a maximal output impedance of 10 Ω . Secondary amplification of 80dB was performed with an input impedance of 1G Ω , and a band-pass of 0– 2000 Hz. All EMG amplification was performed using a power less than 12V DC. EMG recordings were sampled at 840 Hz	-	Performance was significantly worse for the seat deemed uncomfortable with vibration ($p < 0.05$)
7	Balasubramanian <i>et al.</i> [18] Subject: 5 professional car drivers. 6 college students with no professional driving experience. Condition: S, 15 minutes	Parts: Right splenius capitiis (RSC), right trapezius (RT), right medial deltoid. (RMD) Setting: EMG signals were recorded using EMG machine (Bagnoli-8TM, Delsys Inc., USA) with single electrode configuration. EMG signals were sampled at 1 kHz, the fifth level of decomposition of the signal using wavelet corresponds to the frequency band of 15.6–31.3 Hz. EMG machine was adjusted to 1000 at the sampling frequency 1000 Hz. The EMG machine was powered by an isolated medical grade power supply with leakage current less than 10 mA and safely isolated to 3750Vrms. The collected EMG signals were filtered using a sixth-order band pass filter with a pass band range of 15–500 Hz.	Electrocardiogram (ECG), electroencephalogram (EEG) and electrooculogram (EOG). Physiological parameters such as pressure, respiration rate and oxygen debt.	Two groups of professional and non-professional drivers participated in this study. Statistically significant ($p < 0.05$) change in the muscle activity is found in both the groups during a short duration (15 min) of gaming.
8	El Falou <i>et al.</i> [19] Subject: 11 drivers Condition: L, 150 minutes	Parts: cervical ES, ES, EO, and TA muscles. Setting: Surface EMG signals were pre-amplified in two stages for a total gain of 80 dB, with a band-pass of 20–2000 Hz. Surface EMG recordings were sampled at 840 Hz, with an anti-aliasing filter of 350 Hz	-	This study was effective in terms of both segmentation and classification, with a low error rate of less than 8% obtained. This error rate could be enhanced by concentrating on the step related to the rejection of non-EMG segments.
9	Durkin <i>et al.</i> [20] Subject: 8 drivers (4 males, 4 females) Condition: S, 1 hour.	Parts: From the right and left thoracic and lumbar ES musculature Setting: EMG signals were differentially amplified (common mode rejection ratio (CMRR) 115 dB, input impedance 10 GO) providing a+4V pp. output (model AMT-8, Bortec, Calgary, AB, Canada), pre-filtered with a bandwidth of 10 – 1000 Hz and digitally sampled at 2048 Hz with a 12 bit+2.5V A/D system.	Seating comfort, muscle oxygenation, muscle blood flow	EMG findings were not statistically significant. Longer driving protocols and corrections for muscle temperature effects may reveal greater differences between massage conditions; however, this study does indicate that the use of massage units whilst driving contributes to a reduced discomfort level, increases the muscle oxygenation and blood flow and the prevention of muscle fatigue during prolonged sitting with no negative impact on driver performance.
10.	Venugopal <i>et al.</i> [21] Subject: 50 workers Condition: A, NR	Parts: BB Setting: Using a bio-amplifier system, the acquisition system has a minimum common mode rejection ratio of 110 dB and a signal to noise ratio of 89 dB. The resolution of the acquisition system ADC is 24 bits. A sampling rate of 10 k samples per second and a gain of 1000 are used for this study. The mean removed signal is filtered using a Butterworth band pass filter of range of 20 – 400 Hz and a notch filter of 50 Hz.	-	Results show a reduction in the mean and median frequencies of the signals under fatigue. Meanwhile, for the mean and variance of the features, they differ by an order of magnitude between the two cases considered. The number of features is reduced by 45% with the genetic algorithm and 36% with the information gain-based ranking. The k-nearest neighbour algorithm is

				found to be the most accurate in classifying the features, with a maximum accuracy of 93% with the features selected using information gain ranking.
11.	Hostens & Ramon [7] Subject: 22 drivers Condition: 60 minutes	Part: Trapezius and deltoid muscles from both left and right side. Setting: A bipolar EMG device (ME3000p8, Mega Electronics Ltd., Finland) was used to continuously register the electrical activity. The signals were pre-amplified (analogue differential amplifiers, preamplifier gain 375, Common Mode Rejection Ratio (CMMR) 110 dB), filtered using a band pass filter (8–500 Hz) and sampled at 1000 Hz.	-	EMG was captured from the left and right trapezius and deltoid muscles, during repetitive, non-continuous, driving tasks (gearing and steering) and the active parts were separated from the non-active parts. Meanwhile the Muscle stiffness was reported by more than half of the subjects after a 1 h drive. Only for the active parts a significant decrease of the MF was seen. However, the EMG amplitude also decreased significantly.

3.4 Summary of Past Studies on EMG

In general, all past studies reviewed in this paper had investigated different muscle parts in variety of applications. Arora & Grenier [14] had investigated whether whole body vibration (WBV), the direction of perturbation and delay between exposure can influences the trunk muscle response in the abdomen and back part among drivers. Meanwhile, Jagannath & Balasubramanian [13] had investigated the driver fatigue by using a few objective methods and measured muscle activity at the head, shoulder, arm and forearm and back. El Falou [17] had studied the evolution of indices of fatigue, discomfort and performance of subjects seated for long duration on the car seats and measured muscle activity at the abdomen and back. Balasubramanian *et al.* [18] had analysed muscle activity changes in the shoulder and neck muscles. El Falou *et al.* [17] had developed an automatic segmentation method in order to identify postural surface EMG segments in long-duration recordings by measuring muscle activity at abdomen, leg and back. Durkin *et al.* [20] had examined the effects of three types of lumbar massage units on sitting comfort and on fatigue of the erector spinae musculature at the back. Hostens & Ramon [7] had examined the driving activity under controlled environment and measure muscle activity at shoulder only.

Balasubramanian & Jagannath [8] had focused on motorcyclist activity and measure EMG at the head, shoulder, arm, forearm and back. Fuller *et al.* [15] had measured the kinematics of postural control and repetitive upper limb movement during standing surface perturbations and in the presence of fatigue. Dong *et al.* [2] had proposed a method to assess overall fatigue of human body movement and measure muscle activity at two main parts, shoulder and arm. Venugopal *et al.* [21] had differentiated sEMG signals under muscle fatigue and non-fatigue conditions with multiple time window features by measuring arm part. Overall, shoulder and back are preferred body parts that had been examined in majority of past studies in this paper.

4.0 CONCLUSION

In the past, there has been considerable research carried out regarding human fatigue. Cumulative physical fatigue can lead to musculoskeletal disorders. Therefore, monitoring and tracking fatigue are of high significance in order to prevent the development of such disorders. All in all, there are two approaches in conducting EMG experiment, either in the

laboratory by using a simulator or in the actual condition. A study design for each study depends on the involvement of the body parts, according to the objective of each study. In addition, some past studies had mentioned the correct procedure to attach EMG electrodes to the muscle. This setting is very important in order to obtain accurate and reliable data. Therefore, the extant past literature in this study had provided an insight to evaluate physical fatigue by using EMG.

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