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Exploring study protocols examining muscle fatigue among transportation and transshipment operators: a systematic review

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Abstract

Transportation and transshipment are essential to logistics, which is necessary for enhancing economic growth. Work-related muscle fatigue is widely acknowledged as one of the significant contributors to losses in occupational safety and health. This study was conducted to review applicable electromyography examining protocols and indicators. Three of the available relevant electronic databases were systematically searched, as well as other search engines with a total of 733 articles found. Only 13 articles were considered corresponding to the inclusion criteria. Examining protocols in muscle fatigue assessment were used during real-time, several sessions, before-after of the operation and the simulation tasks. Time domain (Root Mean Square: RMS, muscle activity, Maximum Voluntary Contraction: MVC) and frequency domain (Mean Frequency: MNF, Median Frequency: MDF) functioned as fatigue EMG indicators. The Real-time protocol appeared to provide the most comprehensive information, required for an intensive result. Although less information was collected, other study protocols still showed their capability of muscle fatigue investigation, particularly in some cases with limitation from real-world operation tasks.

1. INTRODUCTION

Transportation and transshipment have always been essential to trading and traveling of people and goods since in the past, present and beyond. This sector has shown constant growing in its business, which is reflected through its revenue. In the year 2015 alone, as much as $1.6 trillion was obtained from the sector's revenue (Downie, 2016).

According to the U.S. National Transportation Safety Board (NTSB), fatigue accounted for 20% of all 182 major transportation-related accidents, documented during 2001 – 2012 (Jeffrey H Marcus & Rosekind, 2017). With the current fast industrialization rate, the number of people and amount of goods involved with the sector seems to be increasing even further, which could lead to a proportional worsening of the safety and health situation.

Work-related muscle fatigue is widely recognized as one of the major causes of accidents and fatalities in the workplace. It can be described as the physical phenomenon in which there are decreases in strength, performance of the task, exercise capacity, person ability to exert force and power output (DG Allen & Westerblad, 2001; Edwards, 1981; Lorist et al., 2002). These occur as a result of an insufficiency in oxygen and nutritive substances supplied through blood circulation, which are associated with changes in the efficiency of the nervous system (Mario Cifrek et al., 2009)

With the ability to evaluate muscle fatigue via changes in electromyography (EMG) signals, occurring over sets of muscular cells known as muscle fibers; surface EMG technique is capable of assessing muscle fatigue while one is performing the tasks in real-time. This is an advantage that other methods, such as EMG invasive technique and PH change measured via blood tests, are not capable of.

Nowadays, surface EMG is gaining greater attention among researchers who work in muscle fatigue investigation. To interpret the obtained EMG signals accurately, the comprehensiveness of the information collected is required. However, there are many conditions as well as some real-world limitations that likely complicate the EMG data collection, which in other words could disturb the accuracy and reliability level of the results. There are many factors that could potentially alter the assessment outcomes, particularly in this transportation and transshipment sector. This study was conducted in order to give clearer insights on all the possible protocols and EMG indicators that are needed for the investigation of muscle fatigue.

2. MATERIALS AND METHODS

2.1. Search strategy

This systematic review was conducted in compliance with the commonly-accepted PRISMA principles (PLoS_Medicine, 2009). The literature searches were carried out during September 2017; across 3 available and widely accepted electronic databases, including: ScienceDirect containing 3,800 academic journals (ScienceDirect, 2018), Pubmed containing 4,500 biomedical journals (University of Pennsylvania's libraries, 2018) and Springer Link containing 3,492 academic journals (Springer Link, 2018). The key-words used were: “muscle fatigue”, “electromyography”, “transportation”, “transshipment”, “vehicle operators”, “drivers”. These terms were used for all databases with their appropriate Boolean operators (such as “AND” and “OR”).

Furthermore, additional literature searches were also performed over a search engine (Google), using the same key-words as mentioned above, as well as the relevant articles from the reference list. Only full papers were acknowledged as eligible for inclusion. Those formats with incomplete or insufficient information, such as abstracts published in conference or workshop proceedings were not included.

2.2. Screening and eligibility criteria

After the duplication removal process, the remaining articles were screened based on several criteria for the exclusion as follows:

- Unrelated to the subject.

- Not written in English.

- Publication before 01-01-2004.

- Full-text inaccessible or unavailable.

- Studies not linked to transportation/transshipment although the associations with muscle fatigue assessment.

The remaining articles were included if they met with the following criteria:

- Studies focusing on muscle fatigue assessment and associated precisely with occupational tasks. Other purposes such as engineering design, agriculture, medical procession, signal processing were excluded.

- Studies involved with muscle fatigue assessment in operators controlling transportation/transshipment-associated vehicles.

3. RESULTS AND DISCUSSION

3.1 Study selection

After screening and eligibility processes, thirteen articles were considered relevant to the study topic. The entire details of the selection criteria processes are summarized in Figure 1.

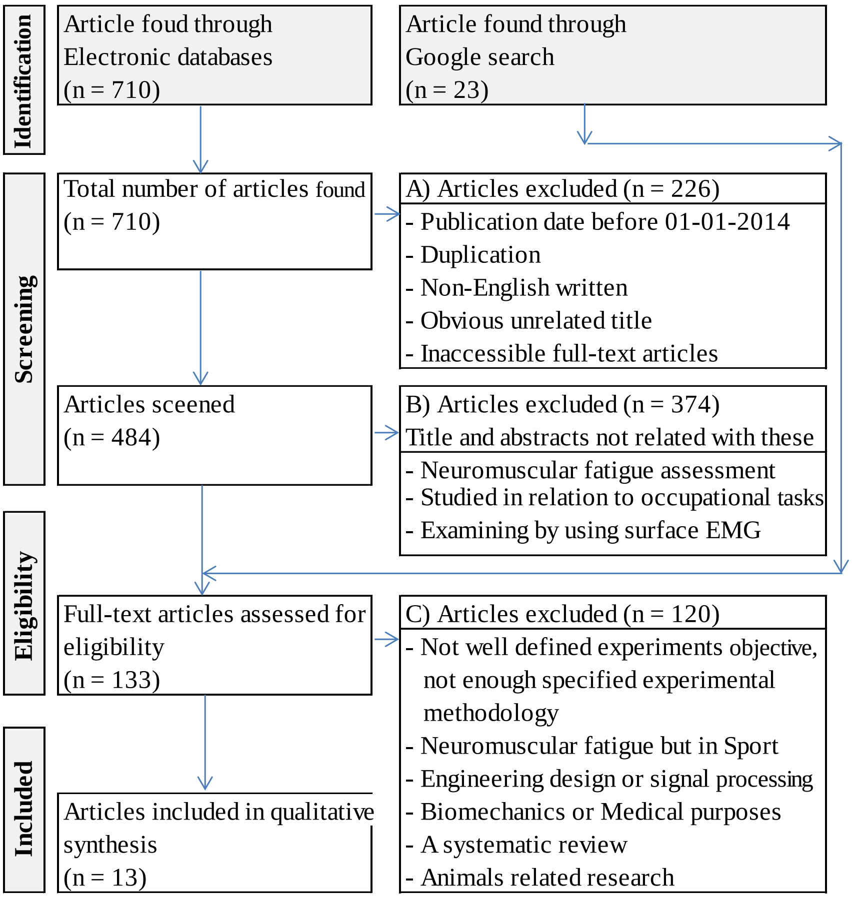

Figure 1. Details of studies selection and inclusion criteria

3.2 Muscle fatigue assessment in operators controlling vehicles considerably linked to transportation/transshipment

Nine studies were found conducting on land transportation/transshipment-related tasks and other four on air transportation. Table 1 and Table 2 present all important information obtained from these studies, assessing muscle fatigue in operators in land and air transportation/transshipment respectively.

Table 1. Studies of land transportation/transshipment associated vehicles (9 studies)

Article title (Location) [vehicle]	Subjects (SJ) and Investigated muscles (IM)	Examination type (ET) and Measuring methods (MM)	Instrument type (IT) and model (MD)	EMG indicts by time (TD) and frequency domain (FD)	Result & Interpretation by EMG indicts when fatigue developed (TD: increase) and (FD: decrease)
Back and neck extensor loading and back pain provocation in urban bus drivers with and without low back pain (Finland) [Bus: urban bus in local city-traffic] (Leinonen et al., 2005)	SJ: 40 voluntary urban bus drivers with (25) and without (15) recent low back pain IM: Lumbar paraspinal and trapezius muscle	ET: real-time MM: MVC and EMG amplitude of back and trapezius muscles were measured before driving and during the drive for a 7hr driving period.	IT: Bipolar surface EMG MD: Portable ME 3000p; Mega Electronics Ltd., Kuopio Finland	TD: RMS, MVC, myoelectric activity FD: no test	TD: noticeable FD: no test Interpretation: Average paraspinal myoelectric activity during driving was approximately 1% of MVC in both groups. Average trapezius myoelectric activities while driving were noticed from 2 to 4% of MVC. Low back and neck-shoulder fatigue increased during driving in both groups particularly in positive vibration pain provocation
Assessment of muscle fatigue in low level monotonous task performance during car driving, Belgium (Belgium) [Car: Fiat scudo 1.9 tD] (Hostens & Ramon, 2005)	SJ: 22 male subjects participated in the tests. IM: left and right trapezius and deltoid muscles	ET: real-time MM: Every subject drove for 1 hr. on only left turn with chosen private route which was set up for this monotonous task.	IT: Bi-polar surface EMG MD: ME3000p8 Electronics Ltd., Finland)	TD: Amplitude (RMS) FD: MNF	TD: noticeable but inverse (decrease) FD: noticeable Interpretation: Only for the active parts, significant decrease of MNF was observed but for the EMG amplitude, decrease was observed instead of increase. This meant no extra recruitment of motor units (MU) and potentiation of these muscle fibers (I-type).
EMG-based analysis of change in muscle activity during simulated driving (India) [Car: Simulation] (Balasubramanian & Adalarasu, 2007)	SJ: 11 male subjects consisting of 5 professional race car drivers and 6 college students IM: Bilateral of Medial deltoid trapezius type II fibers and splenius capitis (MNF)	ET: simulation MM: A 15 min trial run followed by 15 min break was set up for all subjects. Then the simulated drive for 15 min was performed with strict preferred posture. EMG signals were extracted at 1st and 15th minute.	IT: Bi-polar surface EMG MD: EMG acquisition device Bagnoli-8TM, Delsys Inc., USA)	TD: Muscular activity FD: no test	TD: noticeable FD: no test Interpretation: Significant changes in muscular activity were found in such short duration between 1st and 15th min. They were observed in left deltoid, bilatal trapezius and splenius capitis muscle groups.
Assessment of early onset of drivers fatigue using multimodal fatigue measures in a static simulator (India) [Car: Simulation] (Jagannath & Balasubramanian, 2014)	SJ: 20 male participants. All had license for more than two years. IM: Bilateral of Trapezius medial (TM), Latissimus	ET: simulation MM: A 30 min driving practice was allowed for getting accustomed followed by a 20 min break. Then all participants were required to perform a 60	IT: Bi-polar surface EMG MD: 16 channel EMG wireless Myomonitor IV, Delsys Inc.	TD: Mean RMS values FD: no test	TD: noticeable FD: no test Interpretation: Significant differences (r < 0.05) were found in TM, LDM and ES muscle groups between the initial and driving period. No significant differences were observed in

Article title (Location) [vehicle]	Subjects (SJ) and Investigated muscles (IM)	Examination type (ET) and Measuring methods (MM)	Instrument type (IT) and model (MD)	EMG indicts by time (TD) and frequency domain (FD)	Result & Interpretation by EMG indicts when fatigue developed (TD: increase) and (FD: decrease)
	dorsi medial (LDM) and Erector spinae (ES)	min drive on a simulated high way with low traffic density, while sitting in their comfortable posture.			other muscle groups.
Assessment of Muscle Fatigue during Driving using Surface EMG (Greece) [Truck, Trailer truck, Tractor] (Katsis C.D. et al., 2004)	SJ: 10 healthy male volunteers including 3 Truck, 3 Trailer-truck and 4 Tractor drivers. IM: left biceps (LB), right biceps (RB) left forearm flexor (LW) right forearm flexor (RW) and frontal (L) muscles	ET: before-after MM: All drivers drove twice in a predefined route around the city of Torino. Measurements were performed at the starting and end points of the route where the vehicles were stopped.	IT: Bi-polar surface EMG MD: A nova Corder V2 Portable PC Polygraph	TD: RMS FD: MDF, MNF	TD: noticeable FD: noticeable Interpretation: Considering at after-test, the MDF and MNF values decreased by 9.5%-18.9% and 11.3%-18.4% from their before-test respectively. For the RMS value, it increased from the before-test by 25.1%-47.7%
Multidisciplinary Study of Biological Parameters and Fatigue Evolution in Quay Crane Operators (Italy) [Quay crane: Simulation] (Fadda et al., 2015)	SJ: 8 quay crane operators working in two different Italian ports IM: Trapezius and lumbar paravertebral muscles (spinal erectors)	ET: simulation MM: All subjects seated in the cockpit. EMG signals were Collected over 4 hr session, with simulated variable environmental conditions. Mean muscle activation of each muscle was then acquired.	IT: Bi-polar surface EMG MD: mega ME6000	TD: mean muscle activation FD: no test	TD: noticeable but inverse FD: no test Interpretation: Six operators out of eight were found reductions of mean muscle activation on neck-shoulders and lumbar muscles.
Evaluation of Forearm Muscle Fatigue from Operating a Motorcycle Clutch (USA)[Motorcycle: simulation] (Megan O. Conrad & Marklin, 2014)	SJ: 23 participants including: 12 females and 11 males volunteers without reports of upper extremity MSDs or injuries. IM: Flexor Digitorum Superficialis (FDS).	ET: simulation MM: Prior to the experiment, an endurance test was conducted at 60%MVC till exhaustion. All participants were asked to perform a simulated motorcycle ride simultaneously with programmed computer game. During the 60 min simulated ride, EMG signals were collected for 5 sec every 5 min.	IT: Bi-polar surface EMG MD: Biometrics DataLink EMG system (Biometrics Ltd., Gwent, UK)	TD: MVC for normalization & reference FD: MNF	TD: noticeable FD: noticeable Interpretation: Percentage of fatigue was calculated using MNF which showed decreasing over time of the endurance test. A significant decrease of fatigue was found 14-31% in male and 27-49% in female for the use of alternate clutch over the existing one.

Article title (Location) [vehicle]	**Subjects (SJ) and Investigated muscles (IM)**	**Examination type (ET) and Measuring methods (MM)**	**Instrument type (IT) and model (MD)**	**EMG indicts by time (TD) and frequency domain (FD)**	**Result & Interpretation by EMG indicts when fatigue developed (TD: increase) and (FD: decrease)**
Monitoring hand flexor fatigue in a 24-h motorcycle endurance race (Spain)[Motorcycle: real-race] (Marina et al., 2011)	SJ: 10 adult voluntary riders. IM: Right hand flexors.	ET: several sessions MM: During the 24 hr race, each rider was asked to have the following tests: MVC and EMG recording at 50% MVC maintaining for 10 sec for each relay which consisted of 6-8 relays between 50 and 60 min duration.	IT: Bi-polar surface EMG MD: ME6000 electromyography system (Mega Electronics, Kuopio, Finland)	TD: Amplitude (RMS), MVC of grip strength FD: MNF and MDF at 50% MVC	TD: noticeable FD: noticeable Interpretation: Normalized MVC/body mass of handgrip trended to decrease overtime from the beginning to the end of the race which in accordance with the normalized MNF and MDF values. Meanwhile, the normalized RMS values were found increasing along the race till the end.
Biomechanical and ergonomic assessment of urban transit operators (Canada)[Bus] (Albert et al., 2014)	SJ: 15 experienced city bus drivers (12 male, 3 female). IM: Neck, upper trapezius and erector spinae	ET: real-time MM: All drivers droved a preselected same bus along a 65 min route at the same time of the day during the tests. EMG muscular activities were measured wirelessly.	IT: Bi-polar surface EMG MD: An 8-channels Noraxon Telemyo 2400T wireless surface EMG system	TD: muscle activity (RMS) FD: no test	TD: noticeable FD: no test Interpretation: Significant differences ($p<0.05$) were found in all muscles assessed except the left lumbar for straight driving, turning right and left period. During the turn period of both right and left, first part of the turn was observed greatly higher than the last part.

Table 2. Studies of air transportation/transshipment associated vehicles (4 studies)

Article title (Location) [vehicle]	Subjects (SJ) and Investigated muscles (IM)	Examination type (ET) and Measuring methods (MM)	Instrument type (IT) and model (MD)	EMG indicts by time (TD) and frequency domain (FD)	Result & Interpretation by EMG indicts when fatigue developed (TD: increase) and (FD: decrease)
Analysis of muscle fatigue in helicopter pilots (India) [Helicopter: Coast Guard] (Balasubramanian et al., 2011)	SJ: 20 helicopter pilots but only 8 associated with EMG. IM: Bilateral of Trapezius, erector spinae	ET: before-after MM: Maximal voluntary contraction (MVC) by lifting of weight on the floor during pre- and post-flight.	IT: Bi-polar surface EMG MD: Bagnoli-8TM, Delsys Inc, USA	TD: Mean amplitude, RMS FD: MF	TD: noticeable FD: noticeable Interpretation: Statistical analysis of TD and FD parameters indicated significant fatigue in right trapezius muscle during flight.
Back Muscle EMG of Helicopter Pilots in Flight: Effects of Fatigue, Vibration, and Posture (Brazil) [Helicopter: Sikorsky S-76 or Bell 412 aircrafts] (Oliveira C. & Nadal, 2004)	SJ: 12 male oil rigs transportation helicopter pilots IM: Right and left erector spinae (ES)	ET: real-time MM: MVC while seated upright in a chair for normalization value. Major data collection was conducted during the 2hr flight for RMS and MDF.	IT: Bi-polar surface EMG MD: (ME3000P, Mega Electronics, Kuopio, Finland)	TD: MVC, RMS, FD: MDF	TD: very low & unclear FD: very low & unclear Interpretation: There was a strong evidence of low muscle activity. No significant difference between left and right EMG was detected during the flight.
Measuring Neuromuscular Fatigue in Cervical Spinal Musculature of Military Helicopter Aircrew (Canada)[CH-146 Helicopter] (Harrison et al., 2009)	SJ: 40 helicopter aircrews: 35 male and 5 female. IM: Right and left splenius capitis (SpCR, SpCL), Right and left sternocleidomastoid (SCMR, SCML), right and left upper trapezius (TR and TL)	ET: before-after MM: Pilots were asked to sit in a standard CH-146 cockpit seat while still on the ground. MVC was tested via isometric movement. Normalized MNF was calculated at the beginning and end of an endurance test, at 70% MVC for 180s.	IT: Bi-polar surface EMG MD: 8 channels system (Bortec Biomedical Ltd., Calgary, Alberta, Canada)	TD: MVC FD: normalized MNF during the endurance test.	TD: used for endurance test FD: noticeable Interpretation: During the endurance test, fatigue was observed (by comparing normalized MNF between start and end) across all examined muscles except upper trapezius. For example: 11-14% in SCMR and SCML and 7.2% and 11.2% for left flexion SpCL and SCML respectively.
Neck and Back Muscle Loading in Pilots Flying High Gz Sorties With and Without Lumbar Support (Finland)[Training jet] (Sovelius et al., 2008)	SJ: 11 Finish Air Force pilots without history of spinal complaints. IM: Sternocleidomastoid (SCM), cervical (CES), thoracic (TES), Lumbar erector spinae muscle (LES)	ET: real-time MM: EMG activities (%MVC) were collected from pilots while flying 2 basic air combat maneuvering sorties with and without individually shaped lumbar support (LS).	IT: Bi-polar surface EMG MD: ME3000P, Mega Electronics, Kuopio, Finland	TD: %MVC FD: no test	TD: noticeable FD: no test interpretation: Comparing between with/without LS being in use, mean percent maximal voluntary contraction (%MVC) was lower, including CES (9%), TES (7%) and LES (8%) when using LS but still not statistically significant.

4. DISCUSSION

Different occupations with different work activities contribute to muscle fatigue in different locations. Most of the muscles affected from fatigue were found from body upper limbs. To investigate fatigue, different examination protocols were used in combination with the interpretation from EMG indications. In order to obtain as most accurate and comprehensive information as possible, the following details have to be taken properly under the different examination conditions

4.1 Examining Protocols

4.1.1 Measuring during real-time operation tasks

Five studies involved with examinations in the car, bus, and training jet were found using this protocol that demonstrated the capability in tracing every bit of muscle activities during the investigation, which very important for the comprehensive interpretations. The study by Albert et al. (2014) illustrated the supreme advantage of this protocol: it could even investigate muscle activities while driving, precisely during the right turn, left turn and straight direction. And in order to implement this examination efficiently, video recording was utilized in the data collection by synchronizing with the EMG measurement.

In many cases, this kind of protocol seems to be the only applicable choice, as presented in the research by Sovelius et al. (2008); they collected EMG signals in high Gz force, produced by the training jet maneuvering during the sorties mission, which obviously no other protocol could have accomplished.

4.1.2 Measuring in several sessions during tasks

The study by Marina et al. (2011) applied this protocol while examining motorcycle drivers during long distance rides. Instead of measuring during the whole duration of the task being investigated, this protocol split the investigation into a series of sessions and accomplished each with sets of the performance test. In this study, the isometric contraction was utilized. Despite not collecting data over the entire activities, it is still possible to trace the development of muscle fatigue periodically over the investigation period. Importantly, all the real-world contributing factors to fatigue, such as vibration, wind impact, stress and so on, are still accounted for the assessment outcomes.

4.1.3 Measuring before-after operation tasks

This protocol was used by the authors of three studies: one involved with the combination of truck, trailer-truck and tractor drivers. Another two studied on coast guard helicopter pilots and military helicopter aircrew; which for both careers, safety is the most important issue first considered. In order to collect as much information from the studied task as possible with less in-work interruption, this protocol appeared to be the only choice left out of the protocols mentioned above. This protocol is similar to the several sessions, except for that obtained EMG signals only indicate muscle fatigue before and after the task. In other words, examining fatigue development at other points during the task is not possible.

4.1.4 Measuring via simulation of operation tasks

When using a simulation of a task, contextual factors are generally easier to control and their effects on the task performance can be better assessed. Four studies were found utilizing simulation of operation tasks protocol: two with cars drivers, one with motorcycle riders and one with quay crane operators. This experimental setup appeared to have restrictions on fatigue contributing factors such as vibration, wind impact, and a reality feeling. Anyways, how useful the simulation is in the study depends on the sophistication of the simulation system itself (Fadda et al., 2015), by which the more sophisticated the system is, the more expensive the experimental operation costs.

Although there are limitations, simulation protocols appeared to be an option for studying operation tasks for which examination in real-world working condition is not allowed or too risky to perform. In addition, this protocol could be used to gain some basic information prior to implementing real-world tests.

4.2 Electromyography indicators

Demonstrating across all included studies, time domain and frequency domain were used as the electromyography indicts in muscle fatigue assessment.

4.2.1 Time domain

Determining of signals in which they change with respect to the continuous time is known as time domain analysis (Y.W. Lee et al., 1950). This time domain can be analyzed through amplitudes of the EMG signals that can be in the forms of Root Mean Square (RMS), muscle activities and Maximum Voluntary Contraction (MVC).

Motor unit action potential (MUAP), innervated from muscle activations (neural inputs), plays a key role in performing muscle movements. While in action, increasing of EMG signals caused by rising MUAPs as well as recruitments of new motor units (MUs), can be detected, as a result, that they are required to overcome those muscle loading (Basmajian J.V. & De Luca C.J., 1985; Sa-ngiamsak, 2016). And as a consequence, when fatigue starts to develop, progressive loss of MVC during the task, resulting from peripheral mechanisms impairment, can be observed (Mellar P. Davis & Walsh, 2010).

Anyways, one study from Hostens and Ramon (2005), which studied monotonous tasks with a very low level of muscle loading, reported that no significant fatigue sight of rising RMS could be observed except ones from the frequency domain. Muscle fibers types being deployed could have been responsible for this outcome, since there are three types: type I (slow-twitch, most fatigue resistant), type IIa (Fast-twitch, fatigue resistant), and type IIb (Fast-twitch, fast fatigable), which each type contributes to fatigue individually (Roberto Merletti & Parker, 2004).

4.2.1 Frequency domain

Determining signals with respect to frequency is called frequency domain analysis (Boashash, 1988). Mean of power frequency spectrum including mean spectral frequency (MNF) and median spectral frequency (MDF) play the key roles as fatigue EMG indicators.

The decrease of MNF and MDF indicate fatigue development, which is a result of the compression of MNF or MDF shifting toward a lower frequency while experiencing the fatigue. This is due to the declination of muscle activations (neural inputs) that are stimulated from the central nervous system (CNS), or on the other hand describable as the reduction of CNS discharge rate (Abbiss CR & Laursen., 2005; Allman & Rice, 2002; Boyas & Guevel, 2011; D G Allen & Westerblad, 2001; Davis & Bailey, 1997; DG Allen & Westerblad, 2001). Indications form this domain could be used as a baseline for the assessment since there are some possibilities of irregular manifestation, which eventually lead to the misinterpretation. This could occur due to various factors such as low-level muscle loading or monotonous (unnoticeable), unbearable fatigue level and pain suffering (inverse manifestation) (Albert WJ et al., 2014; Hostens & Ramon, 2005; Leinonen et al., 2005)

5. CONCLUSIONS

Different occupations with different work activities in transportation and transshipment could lead to muscle fatigue on different locations, depending upon where and how often muscles are deployed. Examining protocols including: during real-time, several sessions, before-after, and simulation were found in muscle fatigue assessment. Time domain (RMS, muscle activity, MVC) and frequency domain (MNF, MDF) functioned well on fatigue assessment as the EMG indicators. The Real-time protocol appeared to provide the most comprehensive information, required for an intensive result. Although less information was collected, other study protocols still showed their capability of muscle fatigue investigation, particularly in some cases with limitation from real-world operation tasks. With appropriate examination protocol, proper information and precise interpretation could be obtained, which in advance preventive countermeasure would be efficiently employed in time.

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