Electromyography Signal Analysis Using Time and Frequency Domain for Health Screening System Task

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Abstract—**Musculoskeletal disorder (MSDs) is one of the most popular issues of occupational injuries and disabilities. It has a big impact and creates a big problem for industries to be resolved. In MSDs, electromyography (EMG) is one of the methods to be studied in order to detect MSDs problem. This research focuses on the EMG signal analysis by using time domain and frequency domain (Welch Power Spectral Density) method. It gives more information from the signal and it is the most suitable method for classifying the moments in order to identify the behavioural of the signals. Axial rotational reach and upper level reach task from Health Screening Program (HST) is performed using functional range of motion (FROM) by considering left and right biceps brachii muscles to be analysed. There are two parameters chosen for each time and for each frequency domain to be tested, which are mean an absolute value (MAV) and root mean square (RMS) for time domain. Median frequency (MDF) and mean frequency (MNF) are for frequency domain. The results showed that frequency domain analysis is able to give more parameter and information of the signal. Upper level reach acquires more effort to perform the task compared to axial rotational reach for left and right biceps brachii. However, different performances of the signal obtained in classifying the moments from t-test analysis due to p-value. The best performance to classify signal characteristics is the lowest p-value which is 7.369E-05 (MAV), 6.9504E-05 (RMS), 0.0054 (MDF). However, p-value for 0.0515 is rejected because it is greater than 0.05. It is concluded that the frequency domain is able to give more information of the signal, however for classifications moments, time domain is better compared to the higher accuracy result. This study is very important to give the idea in the future analysis of EMG signal in the aspect of detecting MSDs in human body in health screening task.**

Keywords—Musculoskeletal disorder; time domain; frequency domain; mean absolute value; root mean square; median frequency; mean frequency

I. INTRODUCTION

ACCORDING to SOCSO which also known as PERKESO, who initiated the nation-wide occupational disease/injury, reported that the Malaysian citizens from non-government jobs were claiming the benefits of Social Insurance [1-2]. SOCSO categorises the industries into manufacturing, service sector, trading, transportation, finance, insurance and agriculture [1]. They classified occupational diseases into hearing impairment, musculoskeletal disorder, vibration disorder, skin diseases and occupational asthma [1-3]. The industrial accidents in Malaysia recorded that 57,639 accidents happened compared to 55,186 for previous year. Musculoskeletal disorder is one of the critical occupational injuries and disabilities [4]. In 2006, the accident

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data showed an increment of 174% from 31 to 85 cases [4]. The effect of MSDs can be prolong from mild to severe disorder [5]. Social security scheme provides medical care and physical/ vocational rehabilitations for workers infected with occupational diseases, injuries, commuting accident and certain non-work-related disease conditions [1-3].

Rehabilitation or rehab is the coordination of medical, social, educational and vocational measures to retrain an individual into the highest level of functional [6][7]. Physical therapy in rehabilitation process assists individuals in recovering from neuromuscular diseases, amputation and disability [6]. Rehabilitation centres provide physical treatment and therapy that help the patients cope with the deficit. Additionally, it reverses many disabling conditions that cannot be done by medical care under the supervision of therapist [5][6]. Due to the physical disability, assistant through the automated technical system could potentially enhance the physical activities of a patient during rehabilitation [6]. Musculoskeletal disorders (MSDs) risk factor mostly cites in the literature including repetition, application of the excessive force, vibration and awkward posture based on compelling evidence that provides a clear link between risk factor and prevalence of MSDs [8].

Generally, the features in EMG signal analysis is divided into three main groups which are time-domain, frequency domain and time-frequency domain [8]. Study of time domain and frequency domain recently become an important in EMG signal analysis. Time domain feature usually is a quick and easy to be implemented because the features does not involving the transformation of raw EMG signal. That is why various researchers have implemented musculoskeletal analysis using time domain. However, the time domain has major limitation in catering non stationary signal with variable amplitude and frequencies [8]. Time domain feature will assume the data as stationary signal [8-9]. Frequency domain is mostly used to study muscle fatigue and motor unit of the recruitment analysis. Musculoskeletal is currently analysed and identified using ergonomist as most awkward and most demand in workstation. Currently, the analysis of musculoskeletal using workstation videos are based on their observation. In frequency domain, Power Spectral Density (PSD) becomes the major analysis and PSD is defined as Fourier transform of auto-correlation function of EMG Signal. However, it is not a good one in computing the PSD in practice because of low accuracy. Therefore, the Welch PSD is introduced to estimate the PSD of the signal.

This paper presents the analysis of EMG signal for axial rotational reach and for upper level reach from health screening test by using time and frequency domain. Welch power algorithm provides a good estimate of power spectral with good frequency resolution [10]. Time and frequency analysis methods are used since it provides higher accuracy and with low computational cost. By applying PSD, the performance of both tasks is analysing clearly especially in muscle contraction and force. Finally, the performance of time and frequency domain is evaluated using t-test. Generally, this paper describes the requirement of time and frequency domain to solve the problems in rehabilitation application such as electromyography (EMG) analysis for health screening system in SOCSO.

II. EXPERIMENT SETUP

Ten subjects are involved in this experiment, however only one subject is been discussed with criteria of 58 kg of weight, 166 cm of height and has previous history of musculoskeletal disorder. There are some parts involved in this experiment setup which are skin preparation, electrode placement (both is based on Surface Electromyography for Non-Invasive Assessment of Muscles (SENIAM) standard) and interfacing (EMG board and Consensus Software) for data collection by using Shimmer 3 EMG Unit.

A. *Task using Functional Range on Motion (FROM) pegboard*

The FROM pegboard consists of 6 panels (left to right): 1, 2, 3, 4, 5 and 6. Each of these panels contains 45 holes with 5 different colours and 3 zones: A, B and C. All of these configurations are shown in Fig. 1. The 3 zones are used to help to identify the 3 main levels of activity: Stooping and Kneeling (ZON C), Standing (ZON B) and Reaching overhead (ZON C). There are five repetitions of each task have been performed by the subjects with 15 peg should be transfer to the corresponding hole before bring it back to the origin. According to the SOCSO standard, fifteen tasks altogether occur in the standard. However, only two tasks involved for upper limb side detection which are axial rotational reach and upper level reach (Fig. 2). Both of these tasks are discussed in this paper and the details of the procedures are as follows:

<u>Axial Rotational Reach</u>

1. The patient is instructed to move a peg from Panel 6 (Zone B) to Panel 4 (Zone B).
2. The patient stood in the centre of the board assembly (approximately 15 inches from the panel) while performing the test.
3. The transfer process required the patient to take the peg out of the hole with the left hand, transfer it to the right hand and then place the peg into the corresponding hole with the right hand, it is called forward order.
4. Once fifteen pegs have been moved, the process is completed in reverse order until all fifteen pegs are restored to their original position (reverse order). This constitutes the completion of one repetition

<u>Upper Level Reach</u>

1. The client is instructed to move five rows of pegs from Panel 2 (Zone B) to corresponding row of holes in Panel 3 (Zone B)
2. The transfer processes required the client to take the peg out of the hole with the left hand, transferred it to the right hand and then place the peg into the corresponding hole with the right hand (forward order).
3. The client started with the highest-level row and then proceeded in order to the lowest level row.
4. Once fifteen pegs have been moved, the process is completed in reverse order until all fifteen pegs are restored to their original position (reverse order). This constitutes the completion of one repetition

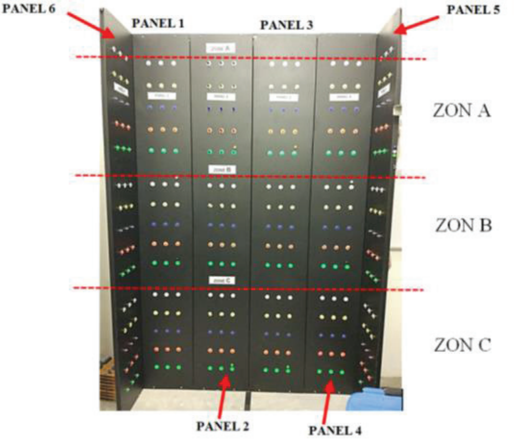


Fig. 1. Functional Range on Motion (FROM)

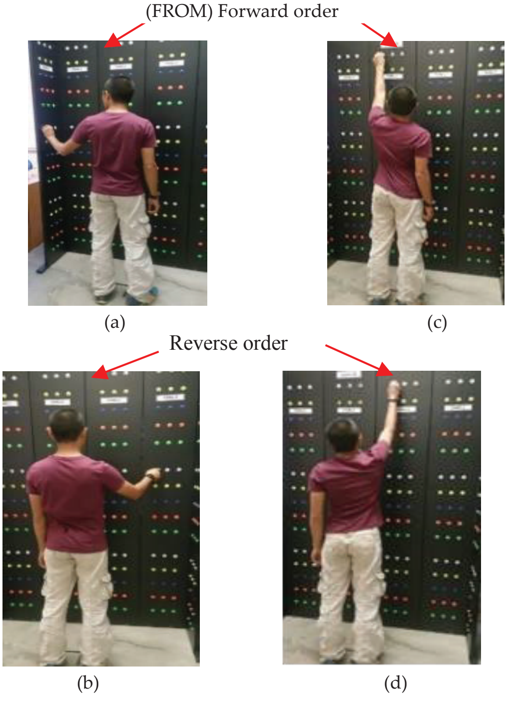


Fig. 2. Procedure of axial rotational reach, (a), (b) forward and reverse order for axial rotational reach and (c), (d) forward and reverse order for upper level reach task

III. METHOD

The raw data from the integrated EMG is used to analyse the performance of the subject. This paper aims to present the analysis of the right and the left biceps brachii for axial rotational reach and the upper level reach in time-domain and spectral domain analysis.

A. Time-domain analysis

Time domain analysis is used as a muscle force detection tool to measure performance of muscle fatigue. Two existing time domain are used to analyse EMG signal, which are mean absolute value and root mean square. Mean absolute value (Equation 1) and root mean square (Equation 2) can be calculated as follow

$$MAV = \frac{1}{N}\sum_{i=1}^{N} | x_i | \tag{1}$$

$$RMS = \sqrt{\frac{1}{N}\sum_{i=1}^{N} x_1^2} \tag{2}$$

where N is for the length of EMG signal, and x_i is the input signal.

B. Frequency Domain

Frequency or spectral domain features are mostly used to measure the muscle fatigue and muscle unit recruitment. Power spectral density (PSD) is the major analysis in frequency domain. Additionally, PSD is an estimated power spectrum of the signal, which describes the characteristic of muscle. Two frequency domain features, mean frequency (MNF) and median frequency (MDF) are used [11].

MNF is an average frequency which defined as the sum of product of the EMG power Spectrum with frequency and divided by total sum of the power intensity. MNF can be calculated as:

$$MNF = \sum_{j=1}^{M} f_j P_j \Big/ \sum_{j=1}^{M} P_j \tag{3}$$

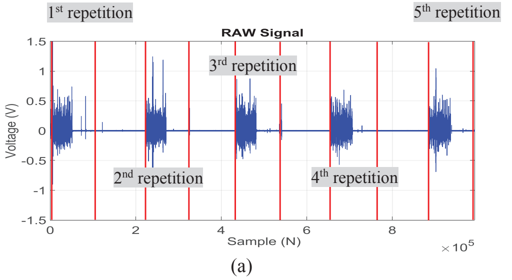
MDF is a frequency at which spectrum is divided into two regions with equal amplitude. MDF can be represented as (Equation 4):

$$\sum_{j=1}^{MDF} P_j = \sum_{j=MDF}^{M} P_j = \frac{1}{2}\sum_{j=1}^{M} P_j \tag{4}$$

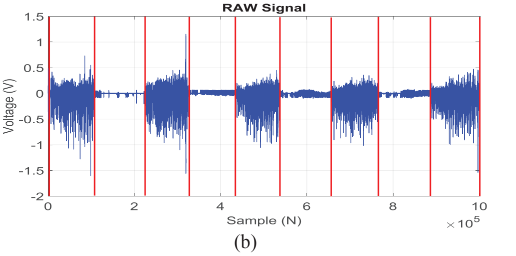
where P_j is the welch power spectral, M is the length of EMG power spectrum and f_j is the sampling frequency.

IV. RESULT AND DISCUSSION

Fig. 3 presents the raw EMG signal of the left and the right biceps brachii for axial rotational reach and the upper level reach task for five repetitions of tasks. This figure is a voltage (V) versus the number of data (N) (in raw signal- time domain). The signal for the left and for the right biceps brachii shows the significant trend of EMG signal in different task and for the axial rotational reach and the upper level reach tasks, it exhibits an almost similar trend which is decreasing of the voltage from the left to the right hands in both tasks. The signals indicated five repetitions of each task performed by the subjects with 15 pegs should be transferred to the corresponding holes (forward order) before take back to the origin (reverse order). Table 1 shows the overall clearer results of the relationship between axial rotational reach and upper level reach tasks.



(a)



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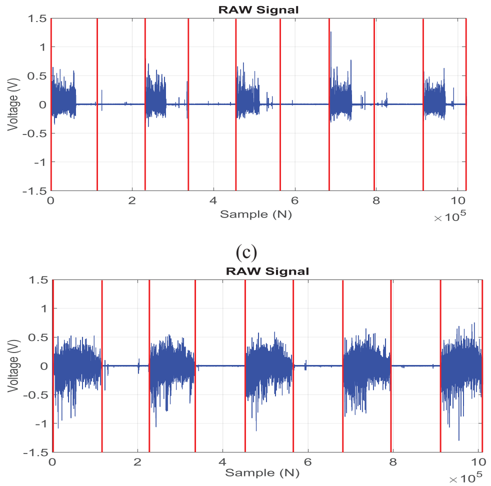


Fig. 3. Raw EMG signal for (a) Left biceps brachii axial rotational reach; (b) right bicpes brachii axial rotational reach; (c) left biceps brachii upper level reach; (d) right biceps brachii upper level reach

A. *Time-domain analysis of EMG Signal*

Table 1 represents the significant difference of the axial rotational reach and the upper level reach for the right and the left biceps brachii which are presented in terms of MAV and RMS. There are the maximum value of raw signal amplitude, mean absolute value (MAV) and root mean square (RMS). All of these parameters are indicating for strength, force and the ability of patients to do the task (muscle fatigue). RMS is related to constant force and non-fatigue contractions, while MAV is indicated for muscle strength.

TABLE I TIME-DOMAIN (RAW) FEATURES ANALYSIS
Axial Rotational Reach

	No. Repetition	Biceps	Max (mV)	MAV (mV)	RMS (mV)
Axial Rotational Reach	1	Left	1.61	0.02	0.06
		Right	1.75	0.08	0.12
	2	Left	1.61	0.02	0.06
		Right	0.26	0.07	0.11
	3	Left	0.87	0.03	0.06
		Right	0.45	0.06	0.09
	4	Left	0.87	0.03	0.06
		Right	0.36	0.05	0.09
	5	Left	0.68	0.03	0.06
		Right	0.47	0.04	0.07
Upper Level Reach	1	Left	2.97	0.39	0.52
		Right	0.75	0.03	0.06
	2	Left	2.70	0.39	0.52
		Right	0.55	0.03	0.06
	3	Left	2.70	0.44	0.57
		Right	0.55	0.03	0.06
	4	Left	2.61	0.49	0.63
		Right	0.53	0.03	0.06
	5	Left	2.61	0.43	0.56
		Right	0.52	0.04	0.08

Based on Table I, some figures are plotted to propose clearer comparison between axial rotational reach, upper level reach for the right and left biceps brachii. The maximum amplitude of both tasks is shown in Fig. 4. Left axial rotational reach (LA), left biceps brachii for upper level reach task (LU), right axial rotational reach (RA) and the right upper level reach (RU) is used as a term in this study.

The trends of the muscles are decreasing to the number of repetition tasks. Subjects has to take out the peg from the board with left biceps brachii, then the right hand take the peg from left hand before placing to the corresponding hole before take the peg into the origin. Between four muscles, it shows the left biceps brachii for the upper level reach and the axial rotational reach task have higher value of voltage produce compared to the right biceps brachii.

The highest amplitude of EMG signal is 2.97 mV for the left biceps brachii upper level reach task. All the muscles involved for both tasks shown decreasing trends of maximum voltage resulted of number repetitions. The left biceps brachii for upper level gain the highest force continued by the left biceps brachii for axial rotational reach, then it is followed by the right biceps brachii. At the first repetitions, axial rotational is higher compared to upper level, however different pattern occurred for second to fifth repetitions which right biceps brachii for upper level reach have the higher maximum value compared to the axial rotational reach. As the result of this discussions, prolong task in workplace can cause discomfort and muscle fatigue. It can be identified technically by observing changes in the amplitude and frequency of EMG signals over time [12].

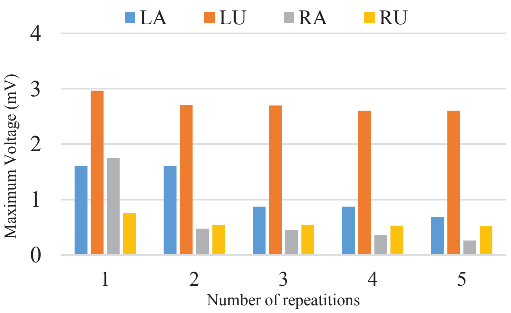


Fig. 4. The maximum amplitude of EMG signal for five repetitions of axial rotational and upper level reaches left and right biceps brachii

Fig. 5 plots the graph of mean absolute value (MAV) and root mean square (RMS) for the right and the left biceps for axial rotational and upper level reach tasks to obtain the strength and the force performance of the muscles. This graph shows stronger left biceps brachii for upper level reach task that required the highest amplitude of voltage with rate 0.39 mV for MAV and 0.57 mV. It shows take out the peg required higher effort before pass to right hand for placing to corresponding hole.

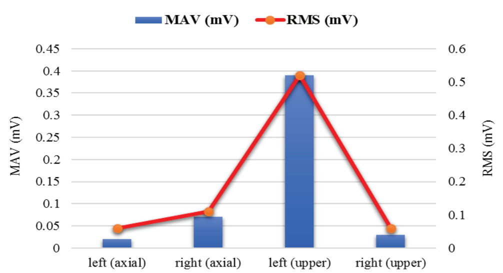
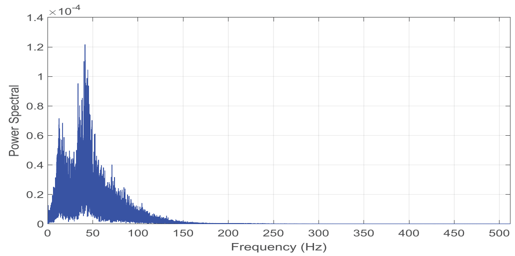


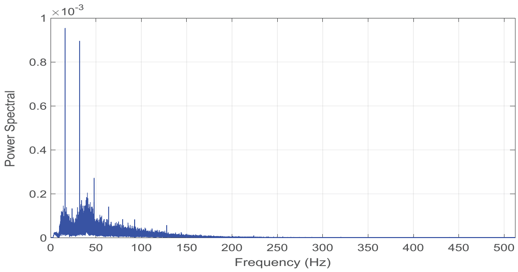
Fig. 5. Mean absolute value (MAV) and root mean square (RMS) right and left biceps relationships in health screening program

B. *Frequency Domain (Spectral) analysis of EMG Signal*

Roughly, there are different performance of the muscles involved in the axial rotational task and the upper level reach task for both time domain and frequency domain. For EMG signal, time domain focuses on time and voltage information; and frequency domain frequency. In this parts, frequency information is used to analyse EMG signals because it is more accurate and is able to gain clearer informations compared to time domain analysis. Power spectral is applied for EMG signal analysis to gain the frequency informations occurred in the signal. Fig. 6 (a) and Fig. 6(b) show welch power spetral for axial rotational reach for left biceps brachii with the highest value is 1.22×10-4 with 41.41 Hz. Then, for the right biceps brachii with the highest welch power spectral of 2.72×10-5 and 48 Hz. The significant of this results is to show the ability to take the peg (left hands) is more effort than to place the peg into corresponding hole. For upper level reach task, both right and left biceps brachii is shown in Fig. 6 (c) and (d). Fig. 6 (c) indicate the highest welch power spectral is 4.59×10-5, 38.53 Hz for the left biceps brachii of upper level reach. On the right biceps brachii, the maximum amplitude is at 8.02×10-5 and 49.7 Hz (maximum frequency compared to others) of frequency.



(a)



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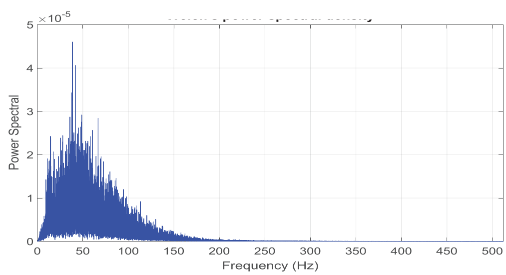
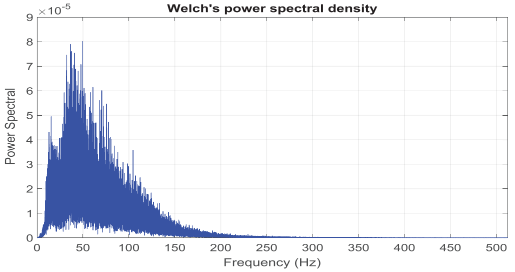


(c)



(d)

Fig. 6. axial rotational reach for (a) right biceps brachii (b) left biceps brachii; upper level reach (c) right biceps brachii and (d) left biceps brachii

Mean frequency (MNF) is the aberage frequency which is calculated from sum of product of EMG power spectral and frequency divided by spectrum intensity. Median frequency (MDF) is defined as frequency divided by power density spectrum that have same amount of power in two regions. Table 2 represents the results of MNF and MDF for biceps muscle performing health screening tasks. Roughly in MNF, it demonstrates that the right biceps brachii is dominant in axial rotational reach and upper level reach task because of the higher force used at the right biceps. Limb movement is an affect moment arm of the muscle is it goes to range of motion, thus affecting external force (torque) output.

TABLE II FREQUENCY DOMAIN FEATURES ANALYSIS

	No. Repetition	Biceps	Mean Frequency (MNF) (Hz)	Median Frequency (MDF) (Hz)
Axial Rotational Reach	1	Left	46.15	39.93
		Right	69.38	48.17
	2	Left	46.15	39.93
		Right	60.18	45.05
	3	Left	48.20	42.01
		Right	74.54	52.46
	4	Left	48.20	42.01
		Right	72.31	53.13
	5	Left	50.49	43.46
		Right	86.40	58.80
Upper Level Reach	1	Left	69.89	58.09
		Right	69.76	57.91
	2	Left	64.35	54.35
		Right	69.76	57.91
	3	Left	65.52	54.85
		Right	72.68	61.28
	4	Left	65.52	54.85
		Right	70.11	59.51
	5	Left	62.50	51.57
		Right	69.56	57.80

The overall performance from Table II is illustrated a clearer in Fig. 7 by considering both MNF and MDF. MNF is the strength of the subjects in performing tasks. This figure presented upper level reach is higher voltage (indicates effort of subjects used to performing task) compared to axial rotational reach. The left biceps brachii for axial rotational reach (LA) is minimum in strength used compared to the other muscles and another task. There are some problems associated with the analysis of EMG recorded during dinamic contractions, which make comparison between the difficult of the subjects to perform the experiments. Biomechanics of muscle movement is transformed as the muscle fibre length during dinamics contraction affecting its generating force due to force-length relationship [15].

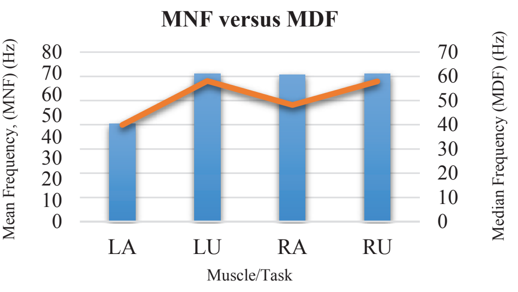


Fig. 7. Mean Frequency (MNF) versus Median Frequency (MDF) for the muscle performance of axial rotational reach and upper level reach task.

By considering all the parameters in frequency information of muscles performances, Fig. 8 is developed. This graph shows the percentage contribution to while over or categories. It will shows the percentage for each value that will contributes over time by considering using 100% of stacked area chart. From this graph, it shows that the right biceps brachii for upper level reach and the axial rotational reach task are higher for placing the peg onto over head corresponding hole with rate almost 100% and 74%. Then, put out the peg form peg board (with left biceps brachii) it shows lower for both tasks with rate 45% for upper level reach and 19% for axial rotational reach.

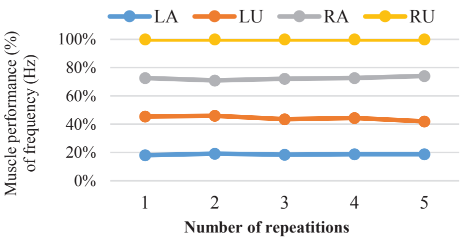


Fig. 8. Muscles performance based on frequency informations

Both of MNF and MDF parameters is capable to offer the extra information compared to time domain, however for the classification of the signal moments involved in HSP, it should identifies which techniques is better to be used either the time domain or the frequency domain.

C. Statistical analysis of EMG signal

It is important to study the behavioural of the signal especially in EMG signals [13]. Classification is the key to get the details about signal behavioural, pattern of the signals and others [13]. In this research, it has a view to know the suitable techniques parameter for signal moment classification, time domain and frequency domain since these features are evaluated using t-test. The statistical difference of 5% is used in t-test. If the p-value is greater than 0.05, it means that there is no statistical different between axial rotational reach and upper level reach tasks.

Table 3 shows the results of t-test analysis for time domain. In classification process, lower of p-value is better performance of parameters. The tolerance p-value is not more than 0.05 to be accepted in t-test analysis. There are four values calculated from time and frequency domain analysis. It shows that mean absolute value (MAV) is the best performance to classified moments of the signal with lowest p-value which is 7.369E-05. It is followed by root mean square (RMS) with 6.9504E-05 and median frequency (MDF) which is 0.0054. However, p-value for mean frequency (MNF) which is 0.0515 is rejected because its p-value is greater than 0.05. This is shown that MNF is not suitable to use for the classification of the moments in order to identify the pattern of the signals.

TABLE III FREQUENCY DOMAIN FEATURES ANALYSIS

	Techniques parameter	P-value (0.05)
Time domain	Mean absolute value (MAV)	7.369E-05
	Root mean square (RMS)	6.9504E-05
Frequency domain	**Mean frequency (MNF)**	**0.0515**
	Median Frequency (MDF)	0.0054

V. CONCLUSION

In conclusion, the analysis of EMG signal using MAV in time domain is reliable to be used for classification of the moments in EMG signal for health screening test (axial rotational reach and upper level reach). The frequency domain is more suitable for detection and for signal behavioural identification. However, both methods are able to detect muscle performance with different task, effort, strength and force used by the subject in performing the specific task.

In the classification of signal's moments, the parameter in time domain is better to be used based on the p-value of t-statistical analysis. The finding in this study is very important as an indicator for more upcoming critical analysis of EMG signal, especially for health screening task to detect MSDs in human body.

This result will help SOCSO to diagnose their patient detail from inside their body based on the physical assessment by considering EMG signal to accurately treat the problematic body parts based on their performance in health screening task.

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