Development of a Muscle Fatigue Index for Motorcyclist in Prolonged Riding

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ABSTRACT

For prolonged motorcycling, it is very common for motorcyclist to experience physiological discomfort such as muscle numbness or strain. These symptoms are known as muscle fatigue and upon continuous occurrences may lead to road accident as reported by a study. Muscle fatigue could be described as a condition where the ability of the skeletal muscle system to exert maximum action is reduced. The objective of this study was to establish a new index system to evaluate muscle fatigue. In determining motorcyclist's perception towards discomfort that leads to muscle fatigue during prolonged motorcycling, survey research using questionnaire tool were performed among the undergraduate students from the Faculty of Mechanical Engineering, Universiti Teknologi MARA Shah Alam. The questionnaires were analyzed via Statistical Package Service and Solution (SPSS) with the level of confidence of 95% (1.96), expected proportion of 0.5 and the precision at 0.1. From the questionnaires, a specialized discomfort rating index system of various body regions for motorcycling named Motorcycling Fatigue Hazard Scale (MoFaHS) was established. The index system allows for the muscle fatigue evaluation of most major body region which are affected during motorcycling to be performed. The following body regions were identified to be the most severely affected (high muscle fatigue rating index): (i) neck/shoulder, (ii) forearm, (iii) upper back, and (iv) lower back. From here, the muscle activities of selected muscles that best represent these body regions were further analyzed via surface electromyography (sEMG) measurement. The data were tabulated and published in two International Ergonomics Conferences as chapter in books. The sEMG measurements were performed on a newly established, filed for patent and award winning Postura Motergo motorcycle test rig setup (bronze medal in the Invention, Innovation and Design Exposition 2014 (IIDEX2014)). With the establishment of the MoFaHS, muscle fatigue could now be quantitatively evaluated.

Keywords: *muscle fatigue, prolonged riding, indexing system, ergonomics.*

Introduction

Fatigue can be classified as the feeling of tiredness, exhaustion, weakness and the inability to maintain the workforce within the human body. Muscle fatigue can be categorized as the decrement of muscle performance of, the failure to maintain attention or unbalanced force development. Muscle fatigue is also described as a condition of muscle in which its capacity to produce maximum voluntary action, or to perform a series of repetitive actions, is reduced. Muscle fatigue is highly risky especially for motorcyclist during prolonged journey. The main purpose of motorcycling is to provide safe journey and also the efficient way from one place to another [1]. Based on the research by PDRM, more than 10,000 riders and their pillion were killed and injured every year in Malaysia [2]. Polis Diraja Malaysia (PDRM) reported that the number of motorcyclist involved in accident increases annually since the year 2004. It was reported that in 2010, more than 14,000 injured and killed in fatal cases and the number of casualties increases each year [3]. This project aimed for the development of a muscle fatigue measuring instrument. The purpose of the instrument is to be used as a tool for muscle fatigue assessment, henceforth, facilitating in the reduction of statistics involving motorcycle road accidents. The determined which potential muscles are being highly affected and the causes of muscle fatigue among motorcyclist during prolonged riding.

Problem Statement

There are several research and literature reviews related to muscle fatigue in prolonged riding for motorcyclist but are not fully documented yet [4]. Some of researchers give a definition of fatigue in term of tiredness or impaired performance. These definitions may valid to motorcyclist but there are still many causes need to be considered

during prolonged riding. Most researchers agreed that the environment and the influence of alcohol or drugs are the main causes of motorcycle accidents, but there are several researchers agreed that muscular fatigue also contributed to the accident. During prolonged riding a motorcycle may cause the rider to feel uncomfortable such as tired and some part of the muscles will feel numb or strains. These symptoms somehow do not have a proper indication or indexing system that can tell motorcyclist that they are experiencing muscle fatigue. Thus the author has developed a motorcyclist fatigue index as an indicator for motorcyclist especially for prolonged riding.

Objectives

Based on the problem statement, the objectives of this project are:

- To evaluate different types of fatigue affected on motorcyclist during prolonged riding.
- To define motorcyclist's perception towards fatigue during prolonged riding.
- To determine suitable index rating to rate the fatigue experienced by motorcyclist.

Scope of Project

Muscle fatigue in prolonged riding for motorcyclist does affect motorcyclist performance and may lead to the increasing of motorcycle accidents. In a way to provide prevention remedy before more motorcycle accidents occur due to muscle fatigue experienced by motorcyclist in prolonged riding, a motorcyclist muscle fatigue index has been developed. Areas of potential muscles being affected and the causes of such muscle fatigue have thoroughly studied to determine which part of the muscles are highly affected. The rating criteria and multiplier to be used in the index have been clearly outlined besides how the index has been used and implemented. Sets of questionnaire to investigate physical or physiological preparations that motorcyclists perform before a prolonged ride is the part of the tools to acquire the data. Effects of exhausted muscles and their severity contribution towards motorcyclist performance are also part of the study. 137 of male students from Universiti Teknologi MARA (UiTM) were involved in this questionnaire. The data obtained is utilized together with another Final Year Project (FYP) student study on the risk level that a motorcyclist might experience if the muscle fatigue index shows a severe rating. This indexing system has the potential and already copyrighted during the project in progress.

Significance of Project

Since the study in fatigue is very important and yet to be documented by any researcher, the author has taken responsibility to study and understand about fatigue and the risk of fatigue during prolonged riding. There are several types of fatigue and may occurred in several ways. By this study, hopefully the author can understand and at the same time give an information related with muscle fatigue to the motorcyclist. It is every road user's responsibilities to ensure their motorcycles and their physical are totally in good condition. The riders should know there are several factors to consider and compensate when riding a motorcycle especially for prolonged riding. Development of this indexing system acted as an indicator that can assist motorcyclist that they are experiencing muscle fatigue during riding. This project is hopefully can give a lot of benefits to human's life especially for motorcyclist. Development of a muscle fatigue index is expected to increase the awareness of the effect and consequences of dangerous riding a motorcycle through muscle fatigue among motorcyclist. Besides that, the development of the muscle fatigue indexing system, hopefully can save many motorcyclist's life also reduce the number of accidents, not in Malaysia only but all over the world.

Literature Review

Motorcycle is the most affordable, preferable and easy to ride as compared to other made of transport. However, accident involving motorcyclists nowadays are increasing each year and become worse during holiday and weekend. The increasing of vehicle on the road during peak hour also contributes accident among motorcyclist. Due to this scenario, there is a need to study the causes of such accidents. Previous studies had identified that amongst the causes of motorcycle accidents are influenced of alcohol, other vehicle violating motorcyclists' right of way, and also motorcyclist fatigue.

There are several definition of fatigue such as sleepiness from performance decrements due to lack of sleep. Fatigue also can occur when the body did not get enough energy when they carry out some activities [5]. The muscle needs to work harder in order to supply continuous energy required for the body. In this project, the author focuses on studying motorcyclist fatigue specifically on muscle fatigue. Sai Praveen Velagapudi et al., mention that the

fatigue due to riding can be divided into 2 major activities performs: 1. Maintain the body position, absorbing road shock 2. Generate the required force to control the motorcycle.

Recently, muscle fatigue studies among motorcyclist are not given enough attention by researchers. Lack of information and data result may contribute to motorcyclist fatigue or subsequent crashes [7]. These symptoms somehow do not have a proper indication or indexing system that can tell motorcyclist that they are experiencing muscle fatigue [4]. In a way to provide prevention remedy before more motorcycle accidents occur due to muscle fatigue experienced by motorcyclist in prolonged riding, a motorcyclist muscle fatigue index has been developed. As seen in Figure 1, the rating of muscle fatigue was developed but there is no indication that can tell motorcyclist experiencing muscle fatigue. This is because muscular fatigue indexing system during prolonged riding has not yet been developed and used elsewhere.

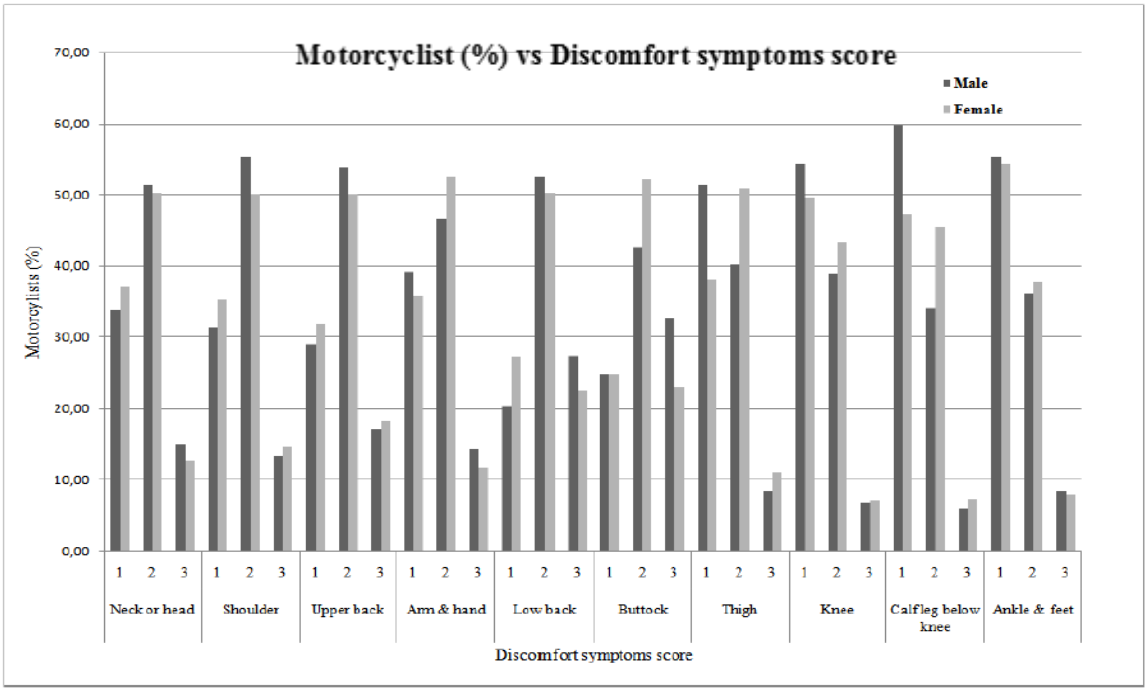


Figure 1: Rating of Muscle Fatigue among Motorcyclist

Previous studies used several tools in collecting their data concerning motorcyclist fatigue. Among the tool that was used by previous researchers are questionnaire surveying tool. This method of data collection happens to be one of the effective way of gathering data from groups of respondents. Moreover, multiple questions asked in the questionnaire can reflect answers in various perspectives. For this particular project, the Borg's scale was widely used in the author's questionnaire. Figure 2 shows the sample of Borg's scale that was modified and included in the questionnaire.

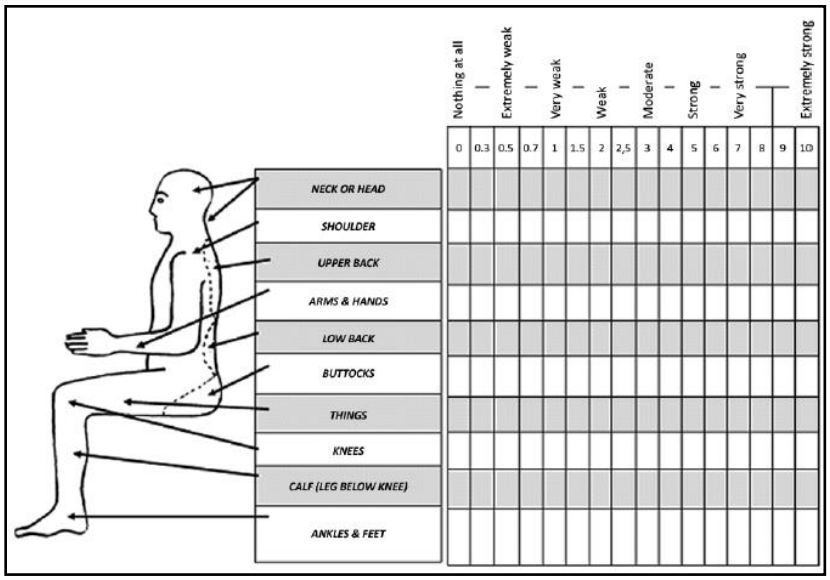
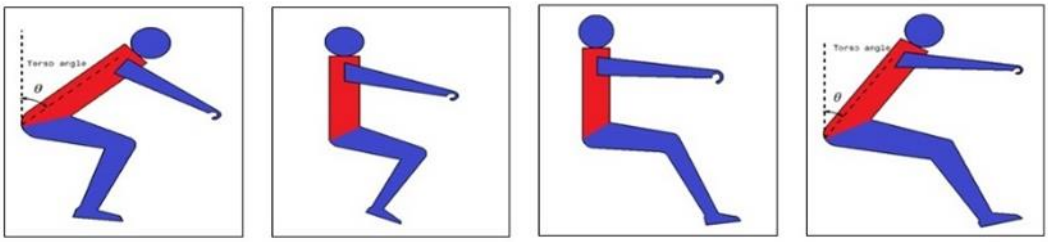


Figure 2: Borg's Scale to Identify Body Discomfort [8]

For the questionnaire that was developed, the author used mixed of closed-ended and opened-ended questions so that the information that was gathered from respondents can be analyzed thoroughly. Closed-ended question provides a list of answers to be chosen by the respondent or known as quantitative data. While open-ended question does not provide any answer to be chosen by the respondent. However, the respondent needs to be independent to give their opinion and also make their own word. This is also known as qualitative data.

Upon studying muscle fatigue on motorcyclist during prolonged riding, body posture is one of the key factor that affects their body physiology. To cater this issue, an established motorcycle test rig was used to assist this study. From a previous study, a standard nomenclature to classify motorcyclist riding posture named as Riding Posture Classification (RIPOC) system [10] was referred by the author to assist the study. In this RIPOC system, four main riding postures were established as RIPOC Type 1 (forward lean riding posture), RIPOC Type 2 (upright riding posture), RIPOC Type 3 (seatback-leg forward riding posture), and RIPOC Type 4 (double forward riding posture). Figure 3 shows the riding postures established in the RIPOC system.



(a) (b) (c) (d)

Figure 3: RIPOC Riding Posture (a) Type 1 (b) Type 2 (c) Type 3 (d) Type 4 [10]

Methodology

Figure 4 shows the flow chart of the author's complete Final Year Project (FYP) that consists of both Final Year Project 1 (FYP 1) and Final Year Project 2 (FYP 2). The detail methodology describing the flow chart are discussed in the following sections.

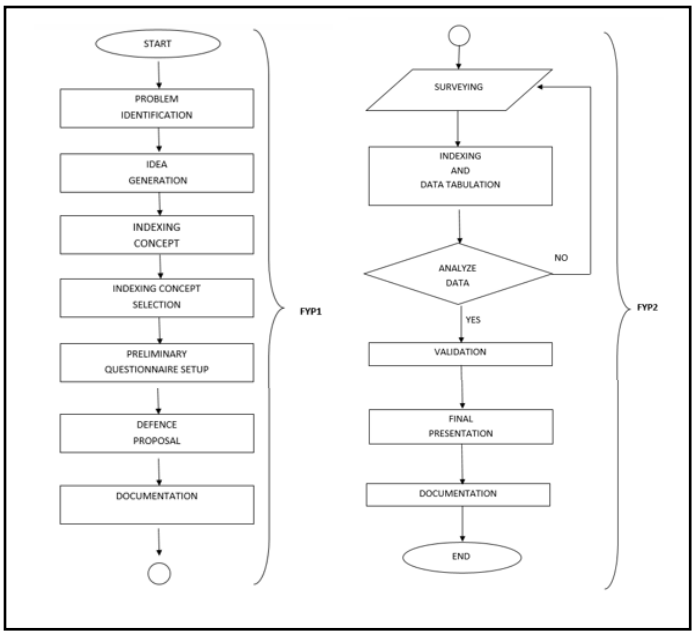


Figure 4: Complete Final Year Project Flow Chart

Initial literatures were gathered by the author to understand the overview and problems relating to this project. The literatures range from several journals, articles, books, and also reliable resources from the websites. From the information gathered, a solid problem identification was established to justify reasons carrying out this project. Then, ideas on developing the indexing system based on the objectives of this project were brainstormed by the author and his supervisor and co-supervisors. To get the idea generation of this project, the author reads, analyzed, evaluated and lastly summarized all related information about this issue. Several established references were also referred to come out with some indexing concepts that suit the aim of this project.

The project continued with the next stage to develop the indexing system. In developing the indexing system, appropriate muscles that may contribute to muscle fatigue among motorcyclist were identified. Current studies were mainly referred to identify those muscles. In parallel, set of questionnaires were developed to acquire respondents' feedback on their motorcycling activities. The questionnaire mainly focused on motorcycling discomfort.

The questionnaires were distributed to 137 of the undergraduate students from the Faculty of Mechanical Engineering, Universiti Teknologi MARA Shah Alam. The survey study aims to determine the public motorcyclists' perception towards discomfort that leads to muscle fatigue during prolonged riding. The questionnaires were analyzed via the Statistical Package Service and Solution (SPSS) with the level of confidence of 95% (1.96), expected proportion of 0.5 and the precision at 0.1 [9]. All of the data that have been analyzed were tabulated in Microsoft Excel to generate results in term of graphs for better understanding of the output.

From the discomfort data that were obtained and analyzed from the questionnaire, the author did a pilot test to validate the results of the feedbacks. The pilot test involved the usage of a MEGA6000 surface electromyography (sEMG) device as shown in Figure 5 that involved 5 respondents. sEMG electrodes were put on the respondents that were asked to sit on a motorcycle test rig. The motorcycle test rig used in the pilot study is an established motorcycle test rig that can be adjusted to replicate various riding postures based on the RIPOC system.

Figure 5: MEGA6000 Surface Electromyography Device

The protocol of the pilot test required every respondent to replicate the four types of RIPOC riding postures for a duration of 5 minutes. Data from the sEMG measurements were captured via MEGAWIN software that was coupled with the MEGA6000 sEMG device. The signals obtained were then analyzed and processed to get 'Average RMS' that reflects muscle activities of the respondents [11]. ASCII file format was used to export the average RMS data to be tabulated in Microsoft Excel to produce results in terms of graphs.

Result from the validation pilot test done by the author, the indexing system to indicate discomfort and muscle fatigue among motorcyclist was developed. The indexing system aims for the assessment of muscle fatigue experienced by the human operator with respect to the duration of time of motorcycling in term of the riding posture practiced, body mass index, fitness level and sleeping patterns. The assessment tool allows for the motorcyclist to predict the risk level anticipated in the event of prolonged riding. This established assessment tool was then named as Motorcycle Fatigue Hazard Indexing Scale (MoFaHS).

Every step and process taken in completing this project were then compiled and documented by the author into a single report for further reference in future studies.

Result

Result from Questionnaire

Table 1 and Table 2 show the respondent details during distribution of questionnaire. Table 3 shows the pain severity rating while Table 4 shows the occurrence moment during prolonged riding. Figure 6 represents the body parts investigated in this study and table 5 shows the result for discomfort rating and moment of occurences for the body parts investigated from the data obtained. The findings from the respective tables and figure are being discussed in the discussion section.

Table 1: Respondents Details

Mean		Standard Deviation	
Age	**Motorcycling Experience (years)**	**Age**	**Motorcycling Experience (years)**
23.61	6.384	1.120	2.7380

Table 2: Respondents details

Median		Standard Deviation	
Height (cm)	**Weight (kg)**	**Height (cm)**	**Weight (kg)**
161-170	61-70	0.671	8.555

Table 3: Pain Severity Rating

PAIN SEVERITY RATING	
0	No Pain
1	Mild Pain, Doesn't Bother
2	Mild Pain, Tolerable Without Medication
3	Mild Pain, Require Medication
4	Severe Pain

Table 4: Occurrence Moment

OCCURRENCE MOMENT	
0	No occurence
1	During The Ride
2	Atfer The Ride/ During Rest/ Days Later
3	Both during and After

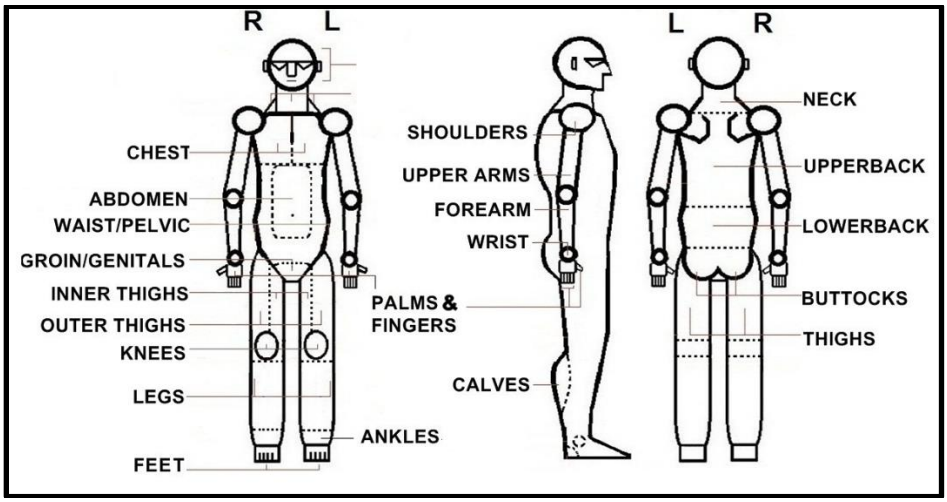


Figure 6 : Body parts investigated

Table 5: Result for Discomfort Rating and Moment of Occurences for The Body Parts Investigated

Type of Body	Rating		Moment	
	Percentages	**Result**	**Percentages**	**Result**
1. Face & Neck	62%	No Pain	57.7%	No occurrences
2. Chest	94.2%	No Pain	92.7%	No occurrences
3. Shoulders & Upper Arms	35.8%	Mild Pain, Tolerable Without Medication	38%	During The Ride
4. Forearm	46.7%	No Pain	46.7%	No occurrences
5. Wrist	38%	No Pain	38%	No occurrences
6. Hands	56.2%	No Pain	54%	No occurrences
7. Abdomen	86.1%	No Pain	84.7%	No occurrences
8. Upper back	40.9%	Mild Pain, Tolerable Without Medication	42.3%	During The Ride
9. Lower back	35.8%	Mild Pain, Tolerable Without Medication	39.4%	During The Ride
10. Groin/genitals	65%	No Pain	63.5%	No occurrences
11. Buttock	40.9%	Mild Pain, Tolerable Without Medication	43.1%	During The Ride
12. Thigh region	73.7%	No Pain	73%	No occurrences
13. Legs, ankles and feet	54%	No Pain	52.6%	No occurrences

The Establishment of Motorcycle Fatigue Hazard Index Scale (MoFaHS)

From the questionnaires also, a specialized discomfort rating index system to assess various body regions concerning discomfort leading to muscle fatigue for motorcycling named Motorcycling Fatigue Hazard Index Scale (MoFaHS) were established. Table 6 shows the newly established MoFaHS assessment tool.

Table 6: Motorcycle Fatigue Hazard Index Scale (MoFaHS)

MOTORCYCLING FATIGUE RISK FACTORS			0-1st hour	1st-2nd hour	2nd-3rd hour	3rd-4th hour	4th hour and beyond
(A)	Riding posture practiced						
	RIPOC Types						
	i)	Type 1	1	3	4	5	5
	ii)	Type 2	1	1	2	3	4
	iii)	Type 3	1	1	1	2	2
	iv)	Type 4	2	3	4	5	5
(B)	Motorcyclist body mass index						
	BMI Categories						
	i)	Underweight	1	1	1	2	2
	ii)	Ideal	1	1	2	2	3
	iii)	Overweight	1	2	2	4	5
	iv)	Obese	2	3	4	5	5
(C)	Fitness Level						
	Lifestyle Categories						
	i)	Rarely/never exercise	2	3	4	5	5
	ii)	Regularly exercise	1	1	2	2	3
	iii)	Athletic	1	1	2	2	2
(D)	Sleeping Patterns						
	Sleeping Pattern Categories						
	i)	Sleep deprived	4	5	5	5	5
	ii)	Sufficient sleep	1	1	1	2	3
	iii)	Oversleeping	1	1	1	2	3

LEGEND	
1	Negligible hazard level
2	Low hazard level, rest session is encouraged
3	Medium hazard level, rest session is encouraged
4	High hazard level, rest session is a must
5	Very high hazard level, rest immediately

Validation from Surface Electromyography (sEMG)

Figure 7 to Figure 11 show the sEMG pilot tests and data that were captured during the pilot test and being tabulated in Microsoft Excel software. The results are findings from the sEMG pilot test that involved only two muscles specifically the left and right upper trapezius (shoulder) muscle and the left and right erector spinae (lower back) muscle, using the RIPOC Type 2, upright riding posture. The graph in the respective figures represent two different respondents. These findings are being discussed in the following discussion section.

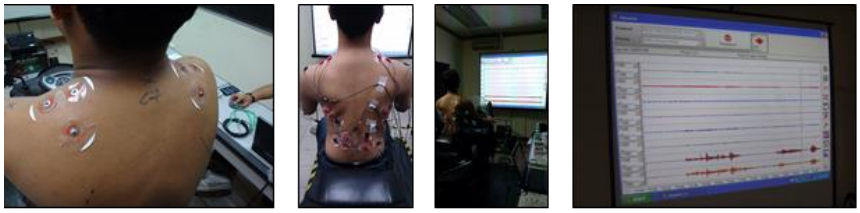


Figure 7: EMG pilot tests in measuring muscle activity using the *Postura Motergo*

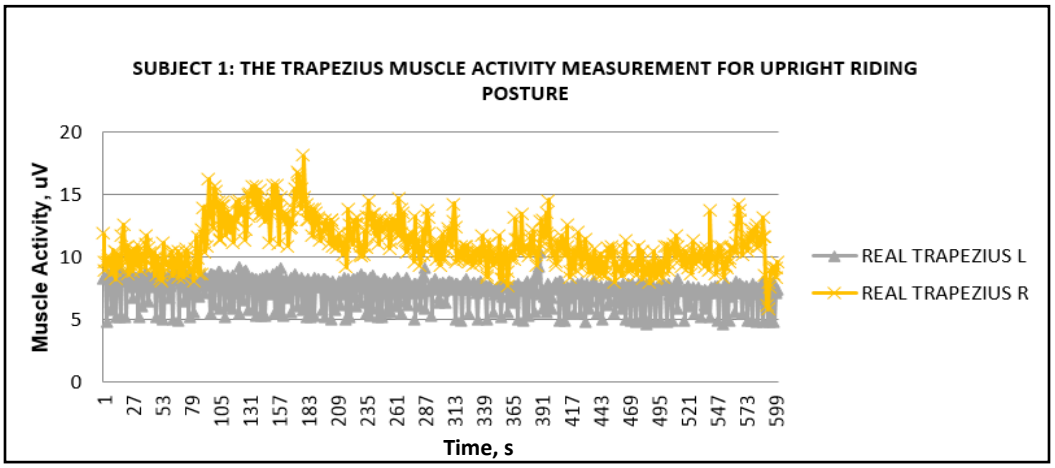


Figure 8: Trapezius Muscle Activity for Upright Riding Posture for Respondent 1

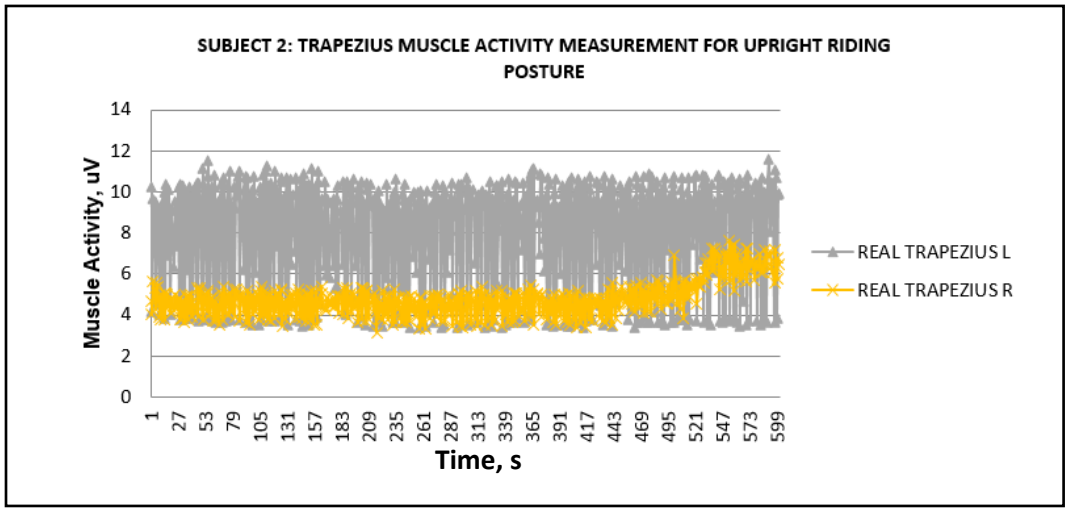


Figure 9: Trapezius Muscle Activity for Upright Riding Posture for Respondent 2

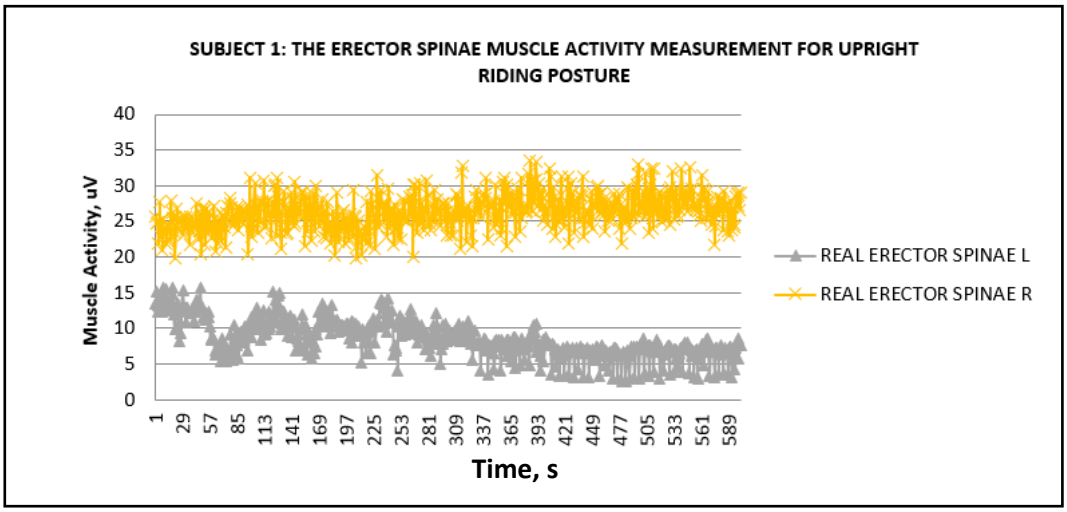


Figure 10: Erector Spinae Muscle Activity for Upright Riding Posture for Respondent 1

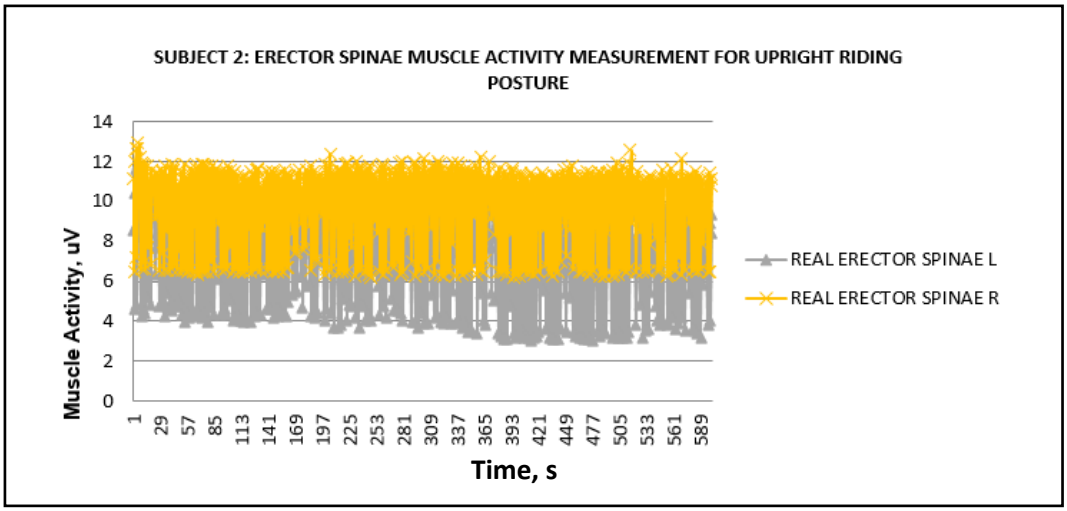


Figure 11: Erector Spinae Muscle Activity for Upright Riding Posture for Respondent 1

Table 7: Sample result for total muscular activation (RMS, uV) of the selected four muscles with respect to the riding postures tested and its percentage (%) of increament incomparison to control for Test Subject 1 (*Note: in citing Ma'arof and Ahmad, 2012)

Test Subject 1			
Riding Posture	**Total RMS (uV)**	**Control (uV)**	**Percentage (%) of Increment of Total Average RMS (uV) with Respect to Control**
TYPE 1	78.6	80.1	-1.8
TYPE 2	209.1	80.1	161.3
TYPE 3	211.2	80.1	163.8

TYPE 4	186.1	80.1	132.4

Discussion

In referring to Table 3 until Table 5, the following body regions were identified to be the most severely affected (high muscle fatigue rating indexed): (i) neck/shoulder, (ii) upper back, (iii) lower back, and (iv) buttock. Motorcyclist always gives reason such as feeling weakness and numbness during prolonged riding. However, further study is required to confirm this reasoning so that any scientific studies that measure motorcyclist muscle fatigue gives reliable and comparable results according to those claims.

Meanwhile from Table 6, the established MoFaHS indexing system allows for initial fatigue evaluation during motorcycling with respect to the factors that contributed towards the development of muscle fatigue. The development of the assessment tool was a result of feedbacks and answers that were filled by respondents. The assessment tool should be used by motorcyclist by referring to the four main parameters that are, (a) riding posture practiced, (b) motorcyclist body mass index, (c) fitness level and (d) sleeping pattern. Based on these four parameters, a motorcyclist can select the element in the parameters that suit their motorcycling activities. By selecting one of the elements, a motorcyclist should know how long they will be riding their motorcycle. By knowing all these information, they can project what is the index score for every elements in the respective parameters. These index score reflect what is the possible hazard level that they may experience during prolonged riding. Henceforth, by establishing this assessment tool, motorcyclists have another alternative method in predicting hazard and risk level during prolonged riding.

To validate the result from the questionnaire that focuses on body discomfort during prolonged riding, surface electromyography (sEMG) pilot test was done in a new established motorcycle laboratory named as Motorcycle Engineering Test Lab (METAL). The main function of the sEMG is to record all muscles activities inside the body. From the data obtained from the questionnaire, the sEMG validated the result given by respondents. This lab is located at level 2, block 2, Faculty of Mechanical Engineering, UiTM Shah Alam. The lab is equipped with an established motorcycle test rig that was used during the pilot test. Data processing and analysis from the questionnaire, SPSS package, and Microsoft Excel were also done in this lab. In referring to Figure 8 until Figure 11, it show that fitness level make a difference with respect to muscle activity with respect to the motorcyclist. Subject 1 regularly participate in various physical activities, whilst, subject 2 rarely participate. Figure 10 and Figure 11, clearly shows the differences in the level of significance with respect to muscle activity as shown by subject 1 and 2. Subject 1 shown less muscle activity for the erector spinae in practicing and maintaining the riding posture for the duration of 5 minutes, in contrast to subject 2. Subject 1 also acknowledged that the level of discomfort experienced during the sEMG measurement was negligible. Subject 2 reported that certain level of discomfort was experienced during the experiment, though, does not require any medication prior to sensation diminishment.

During the project, it was found that there is very limited number of documentations on motorcycle crash due to muscle fatigue during prolonged riding. However, there is still no literature review based on the indexing system for muscle fatigue yet developed. Therefore, this is one of the first study to develop an indexing system of muscle fatigue for motorcyclist in prolonged riding based on questionnaires and related software. In order to validate the result from the questionnaire, alternative solutions by using surface electromyography (sEMG) have been used to prove the result given by respondents. From the questionnaires too, a specialized discomfort rating index system of various body regions for motorcycling named Motorcycling Fatigue Hazard Scale (MoFaHS) was established. The indexing system allows for the muscle fatigue evaluation of most major body region, which are affected during motorcycling to be performed. Besides that, this project also evaluate different types of fatigue affected on motorcyclist during prolonged riding. In order to get information from the respondent, the author has defined motorcyclist's perception first towards fatigue during prolonged riding.

Achievement and Application

During the pilot test, the project has won recognition by receiving bronze winning medalist in the Invention, Innovation and Design Exposition 2014 (IIDEX2014) at Dewan Agung Tuanku Canselor (DATC), UiTM on April 27-30, 2014, the *Postura Motergo* motorcycle test rig was extensively used. The author was one of the team members that helped out to develop the winning test rig that was a great debut for such a designed product. Figure 12 shows the author and the award achieved in the IIDEX2014 event. Besides that, the author also registered as one of the Human Factors and Ergonomics Society Malaysia (HFEM) with a member number 0092 to strengthen his network with professionals in the ergonomics area.

Besides that, the author's project has been presented at the Ergonomics and Human Factors 2014 (EHF) International Conference, Grand Harbour Hotel, Southampton, United Kingdom on April 10, 2014. The project has also published as a chapter book with ISBN9781138026353 in the post-conference book for the EHF2014 conference in the 'Contemporary Ergonomics and Human Factors 2014'. Another paper also will be published as a chapter in book as an indexed post-conference book. It was accepted and to be presented at the 5th International Applied Human Factors and Ergonomics Conference in Krakow, Poland on July 19-23, 2014.

Figure 12: Involvement in Invention, Innovation and Design Exposition 2014 (IIDEX2014)

Conclusion

In conclusion, the neck/shoulder, upper back, lower back, and buttock were identified as the most severely affected body regions during prolonged riding based on the human riding posture, muscle activity and journey duration. All results and data has been recorded and noted based on the feedback from respondents through a set of questionnaire that were validated via the sEMG pilot test in the Motorcycle Engineering Test Lab (METAL). The perception towards fatigue during prolonged riding among motorcyclist have been successfully achieved by collecting data from motorcyclists and information gathered from literatures through UiTM's library database. This objective was carried out with the intention of identifying the perception among motorcyclist about the effects of prolonged riding in terms of muscle fatigue. Finally, the Motorcycling Fatigue Hazard Indexing Scale or MoFaHS was successfully established with suitable index rating to rate the fatigue experienced by the motorcyclist. As a conclusion, all objectives have been successfully achieved.

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