Investigation of motorcycle rider's Ergonomic Discomfort (ED) and Musculo Skeletal Disorders (MSDs) in right wrist due to throttling while driving a motorcycle

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The primary purpose of this study is to assess the present situation related to Ergonomic Discomfort (ED) and Musculo Skeletal Disorders (MSDs) while driving a motorcycle. The Rapid Upper Limb Analysis (RULA) and Numeric Rating pain Scale (NRS) are used in this study. The study is carried out to find the ED and MSDs of the motorcycle users. Thirty motorcycle riders are used for this study. RULA study shows that pain in right wrist (due to throttling) is the most common one. NRS is performed to validate the RULA results. The error analysis of RULA and NRS are found to be 99.77%. The NRS results agreed with the RULA results and also confirmed that motorcycle riders experienced more discomfort in their right wrist than any other body parts during the riding process.

Keywords: RULA, NRS, Motorcycle ergonomics, Wrist pain.

Rapid upper limb analysis (RULA) and numeric rating pain scale (NRS) were used to find ED and MSDs among the motorcycle users. The results shows majority of the motorcycle riders are experienced ED and MSDs

1. Introduction

Motorcycles are among the easiest transportation available in India; In spite of their easy availability, motorcycle causes fatigue and pain on human musculoskeletal system. Studies about fatigue and ergonomics among motorcycle riders are hardly available in literature and research publications. In motorcycle, throttling is done by twisting movement of twist grip, but due to continuous throttle twist when riding in city traffic conditions and long driving on highway creates MSDs. The primary objective of this study to test whether the twisting movement of throttle and body posture creates MSDs.

Physiotherapists and ergonomists quote reason for MSDs and ED. Physiotherapists deal with two types of wrist injuries; one is traumatic injuries and the other is repetitive motion injuries (MSDs). Traumatic injuries results in single traumatic event such as fractures. Repetitive motion injuries are developed by over time riding and are often due to repetitive movement of the arms and hands such as twisting the wrist. Wrist acting away from midline and repetitive work of wrist amplifies wrist pain. Following studies agree with statement of physical therapist's repetitive motion injuries (MSDs)**.** (Sai Praveen Velagapudi and Ray G. 2015) study states that the force exerted to control motorcycle leads to unwanted fatigue as pain. (Helmi Rashid et al. 2015) study also shows that if motorcycle throttle is twisted continuously it creates unwanted wrist pain and it increases wrist pain than any other automotive vehicle throttle. (Anas Shakil 2013) quoted repetitive motion of wrist joint for an extended period of time will develop Carpal Tunnel Syndrome (CTS). And CTS is one of the MDSs. Carpal tunnel syndrome occurred (30 %) more in right hand (presence of the throttle on the right side) as compared to (12%) in left hand.

(Bridger R S 2003) highlighted that the fatigue due to riding can be divided in to two activities subjected to body; one is the body posture while absorbing road shocks for long periods and second is applying the required forces to control the motorcycle. Following studies result agree with statement of (Bridger R S 2003) body posture while absorbing road shocks for long periods. (Karmegam et al. [2009], Robertson and Minter [1996]) studies show lack of ergonomic interaction of human with motorcycle while riding motorcycle causes discomfort on rider's body parts. (Robertson 1985) highlighted that motorcycle riders suffered from discomfort varied among different segments of motorcycles and their different body parts. The study indicates the experimental by riders discomfort mainly in the upper body parts those motorcycle (Sai Praveen Velagapudi and Ray G [2015], Karmegam et at. [2009]). Motorcyclists are exposed to continue static posture which leads to significant angular deviations in almost all body joints and lumbar angle (Koumi Dutta, Bibaswan Basu and Devashish Sen 2014).

This study take into account a body (wrist, elbow, knee, and ankle) parts and determines the value of the variation in the pain of the four operating modes such as - throttling, clutching, braking and gear shifting in motorcyclist body (wrist, elbow, knee and ankle). The observation method – RULA (Rapid Upper Limp Analysis) and self report assessment – NRS (Numeric Rating pain Scale) were used in this study to asses ED and MSDs among motorcyclist. RULA is used for evaluate the risk of work related upper limb disorders of human. To analyse RULA photographic method was used, this method is extensively used for ergonomic study of human body posture. RULA scores are calculated based on body postures, muscle forces and repetitiveness of the work (Mc Atamney and Corlett [1993] and Drinkaus P et al. [2003]). RULA is critically reviewed in these following studies. (Gillian A et al. [2011], Guangyan Li and Peter Buckle [1999], Dohyung Kee and Waldemar Karwowski [2007]) study pointed out RULA shows more precision in assessing posture related loads, when compared with OWAS and REBA. (Iman Dianat and Arezou Salimi 2014) conducted a study with 180 hand sewn shoe workers, to evaluate their working condition and musculoskeletal disorder symptoms by using questionnaire and RULA methods. (Leslie J K Fountain 2003) conducts study to find relationship between RULA and electromyography body surface measure by individual workers discomfort report and job posture questionnaires. RULA was used to assess rider posture in static and dynamic condition of two wheelers.

(Balasubramanian V and Swami Prasad G 2006) used RBG pain scale of 0–5 to asses bar cutters upper extremity pain in their study. The result highlighted that pain is unable to measure directly without an instrument also stated pain can be noted by a questionnaire method. Praveen Velagapudi, Ray G (2015), in this study suggested that questionnaire based discomfort scale and the rehabilitation bioengineering group (RBG) pain scale shall be used to analyse discomfort among motorcycle riders. NRS is one type of pain scale, which is being used to find a pain value of human. Most of the researchers (Sofia Lampropoulou, Alexander V and Nowicky [2012], Williamson A and Hoggart B [2005], Cristina Larroy [2002]) revealed that NRS has good sensitivity and good statistically analyzed tool to measure pain and NRS has reliability than any other pain measurement tools. (Williamson A and Hoggart B 2005) in their study revealed that the numerical rating pain scale could be used graphically or verbally to measure pain. The National Initiative on Pain Control™ (NIPC™)'s 0 to10 Numeric Pain Rating

Scale (NRS) tool was used to find the severity and quality of pain experienced by riders using questionnaire method. (Floyd J and Fowler 1995) highlighted that critical standard for a good question and answer process is that it produces answer that provides meaningful information about what we are trying to describe.

This study is also performed to investigate whether RULA and NRS score were same as estimated by subjects for body posture and questionnaire methods. This study tests this hypothesis and provides data about the right wrist pain from body posture and Questionnaire. The null hypothesis for this study is no difference between NRS and RULA scores.

2. Methods

The following methods are used in assessing present situation related to ergonomics and human fatigue while riding a Motorcycle.

2.1 Rapid upper limb analysis (RULA)

A total of 30 volunteers of motorcycle riders in three different body postures were studied with RULA method. RULA is performed on all three types of motorcycles while they were riding using different motorcycle (Street sports, standard and Scooter). During RULA testing, upper extremity and grand scores of three types of motorcycles are calculated. Score A is derived by addition of shoulder, elbow and wrist, score B is derived by addition of neck, trunk and legs, score C is obtained by addition of muscle use and force of shoulder, elbow and wrist and score D is obtained by muscle use and force of neck, trunk and legs. Grand score is obtained by addition of score C and D.

2.1.1. RULA study samples

A total of 30 volunteers of this study are selected among the students in BSA Crescent University, Chennai, India. Since majority of motorcycle users in India are male, hence male volunteers are alone selected in this study. The volunteers are selected based on their driving experience (such as long distance riders) and licence holders. Those who are riding motorcycles mora than a hour in a day are selected as voluntees. The eligibility criteria for volunteers are riding motorcycle more than one hour per day, volunteers those who were riding less than one hour were excluded from the study. Thirty volunteers anthropometry details are age (Avg.21.13 and SD. 0.56), height (Avg.177.20 and SD.6.37) and weight (Avg.71.07 and SD.10.57). All volunteers are regular motorcycle users as a mode of transport for at least Avg. of 2.13 and SD of 0.98 hours per day and distance travelled at an Avg. of 40.03 and SD of 27.41 Km per day on Chennai roads and are riding for an Avg. of 7.70 and SD of 2.25 years. All volunteers are reported free from wrist, elbow, ankle and feet pain disorders. All volunteers are right-hand dominant, and twist throttle with their right hands. This study is performed with the permission of the all volunteers were explained about the primary objectives of the study.

2.1.2. Types of Motorcycle

Three types of motorcycle are used in this study. The following motorcycle types are selected based on pertinent to the Indian motorcycle market. Motorcycle -1 (Scooter), motorcycle -2 (standard) and motorcycle -3 (Street sports). The types chosen are indented scope to consider the noticed differences in riding position of the motorcyclist. Other types of motorcycles are similar combinations of the above mentioned types (Robertson and Minter 1996).

2.1.3. Posture analysis by photographic technique

To study the body postures a still photograper is used to take the snaps of volunteers (Koumi Dutta, Bibaswan Basu and Devashish Sen [2014] and Dohyung Kee and Waldemar Karwowski [2007]). Volunteers were instructed to sit on the motorcycle in the position where they would feel convenient or comfort (Robertson and Minter 1996). The ideal view angle is used to take snaps of a particular posture of human body. Reason to choose ideal view is that, it produces mainly accurate posture angle and no perspective distortion (Michael H Lau, Thomas and Armstrong 2011).

The motorcycle rider posture could be categorized into static and dynamic condition. Use of RULA is not possible to take snaps of rider in dynamic condition. For this reason dynamic condition is taken in static posture but wrist posture is different as it is fully twisted. Static condition refers to the condition when the rider sits on the motorcycle with comfortable riding position and dynamic condition refers to the condition when the motorcycle starts to move due to throttling same as study of (Ma'arof et al. 2014). Participants are instructed how to perform the task prior taking the snaps. The body posture of all 30 volunteer's statics and dynamics are photographed in sitting position on the motorcycle from ideal view angles. The snaps are considered to be relevant for input to the RULA. Body postures such as wrist, ankle, elbow and knee are obtained by aligning lines drawn on the images to mark with the desired angles by using Autodesk 2016 (fig.1 and fig. 2) (Michael H Lau, Thomas and Armstrong 2011). The angles are marked to represent the range for body posture. Then the static and dynamic postures of rider are compared. Mean of this two postures are calculated and the mean value gives the values for different postures in RULA analysis.

In static condition, normally riders will be holding wrist on twist grip in flexion or extension positions. In dynamic condition, all riders will be holding wrist on twist grip in extension position only. The volunteers' wrist angles varied from flexion to extension in non throttling condition for all the three types of motorcycles, but wrist angle is in extension position in throttling condition for all the three types of motorcycles. The angle between the hand and the forearm for motorcycle 1 is 7.8^o for 57% riders in mean extension and 17.3^o for 43% riders in mean flexion. For motorcycle 2 it is 5.5^o for 40% riders in mean extension and 15.5^o for 60% riders in mean flexion. For motorcycle 3 it is 4.1^o for 30% riders in mean extension and 21.6^o for 70% riders in mean flexion. In throttling condition wrist posture is always in extension. The mean extension for motorcycle 1 is 24.7^o, the mean extension for motorcycle 2 is 26.0^o and the mean extension for motorcycle 3 is 16.3^o. Typical motorcyclist in static and dynamic body postures with various body angles are shown in fig.1 and fig. 2. These angles are used to find RULA scores A. The force required for twist throttle is 20 N is attributed with a score of 1 and this score is added to score A to obtain score C.

2.2 Numeric rating pain scale (NRS)

Numeric rating pain scale is based on self reporting and is collected by questionnaire method. 0 to 10 point Numeric rating scale (Source: National Initiative on Pain Control (NIPC- USA) is used for recording the volunteer's pain orally. The NRS is a 0 to 10 point interval level scale where the starting point 0 means no pain and end point 10 means worst pain. This study uses table that represents the body parts involved on four operating modes during riding i.e., throttling, clutching, braking and gear shifting were wrist, elbow, ankle, and feet (left and right) with 0 to 10 point Numeric rating scale.

2.2.1. NRS study samples

There were 30 volunteers riding type 1, 2 and 3 motorcycles. Volunteers are asked to take one of the following types of motorcycle scooter, standard and street sports. They are asked to perform three tasks with 90 treatment combinations (three types of motorcycle, thirty riders) in a random order. The participants are allotted 40 km to drive the motorcycle, which is based on volunteers' average value of driving distance per day. After the completion of the rides volunteers are requested to rate their pain from 0 to 10 for the 30 motorcycle ride including their wrist, elbow, knee and ankle (Sai Praveen Velagapudi. et al (2015)). All volunteers are allowed to ride only one bike per day to avoid any overlap of pain, three days are taken to complete it. The volunteers have ridden all the three types of motorcycles (Sai Praveen Velagapudi et al. 2010). To find reliability of the NRS tesr, same test is conducted for the same 30 volunteers after a week.

Student t test is used to validate RULA (for body posture) and NRS (questionnaire) scores. Student t test is used to find the hypothesis and provides data about the right wrist pain from body posture and questionnaire.

3. Results and discussions

3.1 With the help of the RULA among the student volunteers

A paired-samples t-test is conducted to compare right wrist pain (ED) in non acceleration and acceleration i.e., static and dynamic conditions for all three types of motorcycle where used in this study. For motorcycle 1, scores are significantly higher for acceleration ($M = 3.17$, $SD = 0.38$) than for the no acceleration ($M = 5$, $SD = 0$), $t(29) = 26.5$, $p < .001$, For motorcycle 2, scores are significantly higher for acceleration ($M = 3.27$, $SD = 0.45$) than for the no acceleration ($M = 5$, $SD = 0$), $t(29) = 21.1$, $p < .001$ and for motorcycle 3, scores are significantly higher for acceleration ($M = 4.5$, $SD = 0.51$) than for the no acceleration ($M = 5.8$, $SD = 0.63$), $t\ (29) = 7.34$, $p < .001$. The frequency of twist has a great impact on the motorcyclists since they determine the intensity of muscular activity involved in motorcyclists. These results suggest that when rider accelerated motorcycle (motorcycle in dynamic condition) really create wrist pain.

One way ANOVAs is conducted to examine which type of motorcycle causes more pain and also to find the differences among the three types of motorcycle riding for score C. There is a significant difference among the three types of motorcycle riding for score C $F\ (2, 87) = 167.24$, $p < .001$ which strongly suggests that one or more pairs of treatments are significantly different. The significant difference of score C is found in all the three motorcycles, the score C in the motorcycle 3 (*M* = 5.13) had higher pain scores compared to the score C in the motorcycle 2 (*M* = 4.13), and 1 (*M* = 4.08). One way ANOVA results are shown in Table 1.

3.2 With the help of the NRS among the volunteers

All 30 volunteers have ridened motorcycle 1, motorcycle 2 and motorcycle 3. However, the order in which they receive this differs. They have randomly split into three groups for counterbalancing and to reduce the bias: group (1) consist of set of 10 volunteers riding motorcycle 1, motorcycle 2 and then motorcycle 3, group (2) the other 10 volunteers riding motorcycle 2, motorcycle 3 and then motorcycle1 and group (3) the last 10 volunteers riding motorcycle 3, motorcycle 1 and then motorcycle 2.

3.2.1 Test-retest reliability Analysis using ICC

To find the reliability of volunteers responses for pain rating, questionnaire are answered by all the volunteers (N=30) at two time with an interval of one week between two tests. To determine the test and retest reliabilities of continuous measurement respondents to volunteers, same pain rating questionnaire at two different times the ICC is performed using SPSS version 24. The significance level is set at $p < 0.05$. The ICC model used is the one-way random effects model single measures. The ICC for all pain rating (wrist, elbow, Knee and ankle) tested for test-retest reliability is good. The ICC (pain rating) = range between 0.796 to 0.904, with [95 % CI 0.615 to 0.800 and 0.898 to 0.954].

3.2.2. Motorcyclist pain score comparison

A total percentage of 30 volunteers' pain rating scores (three types of motorcycle) are presented in Table 2 and Figure 3. It represents the rating of pain on each of their body parts. Table 2 and Figure 3 show the comparison of pain for motorcyclist. This comparison indicated that the motorcyclists experienced different level of pain on different body parts during the riding process. The score rating of 1 to 2 is mild pain; the score rating of 3 to 4 is sensible pain and the score rating of 5 to 6 represents the strong pain.

3.2.3. ANOVAs for different pain rating.

The volunteers have reported of having experienced pain in the wrist mean value (left 2.79 and right 4.46), elbow (left 1.90 and right 2.01), knee (left 2.03 and right 1.96), and ankle (left 2.36 and right 2.09). Meanwhile, volunteers have experienced more pain in wrist. The volunteers have indicated elbow (left 1.90 and right 2.01), knee (left 2.03 and right 1.96), and ankle (left 2.36 and right 2.09) as having less pain in their body parts. The volunteers have indicated that they have experienced more pain in their right wrist shown in table 2 and fig 3. The results of the NRS study confirmed that more than half of motorcycle users had pain in the wrist than elbow, ankle and feet.

A two-way ANOVA (with replication) is conducted to examine 30 volunteers pain rating and relationship between three types of motorcycle and volunteers' body parts pain score. The two independent variables in this study are body parts and types of motorcycle (motorcycle 1, motorcycle 2 and motorcycle 3). Riders' body parts are divided into four groups (left and right) Wrist, Elbow, Knee and Ankle according to motorcycle operation were accelerating, braking, clutching and gear shifting. The results for the two-way ANOVA indicated a significant main effect for body parts, F (7, 696) = 90.21, $p < .001$, a significant main effect for types of motorcycle, F (2, 696) = 85.20, $p < .001$, and the results show a significant interaction between body parts and types of motorcycle, F (14, 696) = 3.55 $p < .001$, indicating that any differences between the body parts are dependent upon the types of motorcycle. Two way ANOVAs (with replication) for pain rating of all three type of motorcycles result in Table 3. Then examine the body parts simple main effects, that is, the differences between riders body parts pain score.

A one way ANOVAs is conducted to explore the mean pain rating on riders' body parts. There is a statistically significant difference at the $p < .001$ level in body parts pain scores for four groups F (7, 232) = 114, which strongly suggests that one or more pairs of treatments are significantly different. One way ANOVAs result shown in table 4. Because the interaction between body parts are significant, we chose to ignore the main effects, instead we first examined the body parts simple main effects, that is, the differences between Wrist(left and right), Elbow(left and right), Knee(left and right) and Ankle(left and right) for the motorcycles riding. Post-hoc comparisons using the Tukey HSD test indicated statistically significant differences between body parts which are shown in table 5 and Non-significant differences are found for the comparisons of body parts shown in table 6. A review of the group means indicated that right wrist (M = 4.46) had a significantly higher level of pain than other body parts.

Additionally, we examined the different types of motorcycle riding, simple main effects, that is the differences among the three types of motorcycle riding for right wrist separately for that two way ANOVAs (without replication) is conducted**.** There is a significant difference among the three types of motorcycle riding for right wrist F (2, 58) = 69.04, p < .001 and there is a no significant difference among the 30 volunteers of motorcycle riding for right wrist F (29, 58) = 1.49, p = 0.095, Follow-up tests are conducted to evaluate the three types of motorcycle riding pair wise differences for right wrist. The significant difference of right wrist is found in the three type of motorcycle riding, the right wrist in the motorcycle 3 (M = 5.2) had higher pain scores compared to the right wrist in the motorcycle 2 (M = 4.53) and 1 (M = 3.63). The two way ANOVAs (without replication) for right wrist pain rating of all three types of motorcycle data in Table 7

These ANOVAs results reveal that all the types of motorcycle developed different level of pain intensity in right wrist also reveals that right wrist pain is more than all other body parts while riding three types of motorcycle with particular time period and distance

The student t-test is conducted in order to determine whether there is a statistically significant difference between the RULA and NRS regarding their reported discomfort symptoms (Table 8). The mean discomfort scores of right wrist between RULA and NRS score differed significantly (t=2.00, df = 57, p *(0.94)* > 0.05) with the NRS score being significantly higher than the RULA mean. The results of student t -test on the RULA and NRS is shown in Table 8. In particular, the wrist score is significant in both RULA and NRS, reflecting high loading of the wrist.

The result shows a significant association between RULA and NRS scores and also shows reported pain, ache or discomfort in the right wrist. In particular, the right wrist score is statistically significant for three types of motorcycle riders, reflecting high right wrist loading. The RULA and NRS scores have expressed higher pain level in right wrist and also the RULA and NRS scores have indicated minimal pain in their elbow, ankle, and feet. For this reason the RULA and NRS scores is used to find out volunteers body posture and also used to find out the volunteers response using self reporting through questionnaires to assess the areas of pain. (Koumi Dutta, Bibaswan Basu and Devashish Sen 2014). Based on this study data, the null hypothesis indicates that there is no difference between RULA and NRS. These findings have implications for observational analysis of right wrist pain. The result points out the need for ergonomics analysis on motorcycle to provide good ride comfort.

4. CONCLUSION

The RULA and NRS are conducted to identify effects of pain and human fatigue affecting a rider while driving motorcycle. The close relationship between the RULA and NRS scores support the possibility of using RULA and NRS as a tool for the assessment of motorcycle rider ED and MSDs. Limitation of this study is different observer may still get different assessment results of the same work, because they may pick up the assessment aspects for different evaluation process within that work. The results suggest that majority of motorcycle riders are suffering more pain on their right wrist than any other parts during their riding process.

5. DISCLOSURE

V.Deepan and Dr. M. Subramaian) declare that there is no conflict of interest regarding the publication of this paper.

6. REFERENCES

Anas Shakil. 2013. "Ergonomics Motorcycle Riding Posture" The Prezi Blog on September 02, 2016. https://prezi.com/0nneqyc0kb2u/ergonomics-motorcycle-riding-posture

Balasubramanian V and Swami Prasad G. 2006. "Ergonomic Assessment of Bar Cutting Process in Construction". Int. J. Industrial and Systems Engineering.

Bridger R S. (2003). *Introduction to Ergonomics*. Taylor & Francis e-Library.

Cristina Larroy. 2002. "Comparing Visual-Analog and Numeric Scales for Assessing Menstrual Pain." Behavioral Medicine 179-181.

Dohyung Kee and Waldemar Karwowski. 2007. "A Comparison of Three Observational Techniques for Assessing Postural Loads in Industry." International Journal of Occupational Safety and Ergonomics (JOSE). Vol. 13, No. 1, 3–14.

Drinkaus P, Sesek , Bloswick D, Bernard T, Walton B, Joseph B, Reeve G And Counts J H. 2003 . "Comparison of Ergonomic Risk Assessment Outputs from Rapid Upper Limb Assessment and The Strain Index for Tasks in Automotive Assembly Plants." Work.

Floyd J and Fowler. 1995. "*Improving Survey Questions Design and Evaluation Applied Social Research Methods series*." New Delhi. India: Sage publications india Pvt.Ltd.

Gillian A, Hawker, Samramian, Tetyanakendzerska, and Melissa French. 2011. "Measures of Adult Pain Visual Analog Scale for Pain (vas pain), Numeric Rating Scale for Pain (NRS Pain), Mcgill Pain Questionnaire (MPQ), Short form Mcgill Pain Questionnaire (SF MPQ), Chronic Pain Grade Scale (CPGS), Short Form 36 Bodily Pain Scale (SF 36 Bps) and Measure of Intermittent and Constant Osteoarthritis Pain (ICOAP)." Arthritis Care and Research. S240–S252

Guangyan Li and Peter Buckle (1999). "Current Techniques for Assessing Physical Exposure to Work Related Musculoskeletal Risks with Emphasis on Posture Based Methods." Ergonomics 674-695.

Helmi Rashid, Muhammad Izzat Nor Ma'arof, RohaniHaron, Wan Muhammad Syahmi Wan Fauzi, Abdul Rahman Omar and RoseleenaJaafar. 2015. "Selection of Muscle Groups for Surface Electromyography (SEMG) Measurement in Analyzing Motorcycling Activity." Journal Teknologi.

Iman Dianat and Arezou Salimi. 2014. “Working Conditions of Iranian Hand Sewn Shoe Workers and Associations with Musculoskeletal Symptoms.” Ergonomics 602-611.

Jelke Bethlehem. 2009. *Applied Survey Methods: A Statistical Perspective.* Published by John Wiley & Sons.

Karmegam C, Ismaild M Y, Sapuana S M, Ismaila N, ShamsulBahrib M T, Shuibd S and Seethae P. 2009. “A Study on Motorcyclist’s Riding Discomfort in Malaysia. Engineering e-Transaction 39-46.

Koumi Dutta, Bibaswan Basu and Devashish Sen. 2014. “Identification and Quantification of Stressors Affecting Motorized Two Wheeler Riders: an Ergonomic Attempt.” International Journal of Research. Granthaalayah.

Lepoutre F X, Roger D, and Loslever P. 1986. “Experimental Analysis of A Visual Postural System in An Office Workstation. In: N. Corlett, J. Wilson amd I. (Eds). 'The ergonomics of working postures'. Taylor&Francis,London.

Leslie J K Fountain. 2003. “Examining RULA’s Postural Scoring System with Selected Physiological and Psycho Physiological Measures.” International Journal of Occupational Safety and Ergonomics 383-392.

Ma'arof, Rashid H, Omar A R, Abdullah S C, Ahmad I N and Karim S A. 2014. "The Motorcycle: A Human Operator Influenced Workstation." Contemporary ergonomics and human factors.

Mark Middlesworth. 2016. "A Step by Step Guide Rapid Upper Limb Assessment (RULA)." Accessed September 02. https://www.ergo-plus.com.

Massaccesia M, Pagnottaa A, Soccettia A, Masalib M, Masieroc C and Grecoa F. 2003. "Investigation of work-related disorders in truck drivers using RULA method." Applied Ergonomics 303–307.

Mc Atamney and E Nigel Corlett. 1993. "RULA: A Survey Method for the Investigation of World Related Upper Limb Disorders." Applied Ergonomics 91-99.

Michael H Lau, Thomas J, and Armstrong. 2011. "The Effect of Viewing Angle on Wrist Posture Estimation from Photographic Images Using Novice Ratters." Applied Ergonomics 634-643.

Naddeo A, Cappetti N and D'Oria C. 2015. "Proposal of a New Quantitative Method for Postural Comfort Evaluation." International Journal of Industrial Ergonomics 25- 35.

Peter M Theuri and Leslie D Turner. 2002. "Conducting Survey Research Through an Enhanced Online Web Survey Procedure." Journal of Internet Commerce 37-53.

Robertson S A and Minter A. 1996. “A Study of Some Anthropometric Characteristics of Motorcycle Riders.” Applied ergonomics.

Robertson S A. 1985. “An Assessment of the Ergonomic Problems of Motorcycle Riders with Special Reference to the Riding Position and Seat Height.” MSc. Thesis, Loughborough University.

Sai Praveen Velagapudi and Ray G. 2015. *Proceedings 19th Triennial Congress of the IE.,* Melbourne.

Sai Praveen Velagapudi, Venkata Mangaraju, Babu R, Venkatesabalasubramanian and Adalarasu K.2010. “Muscle Fatigue Due To Motorcycle Riding.” SAE international.

Sofia Lampropoulou, Alexander V and Nowicky. 2012. “Evaluation of the Numeric Rating Scale for Perception of Effort during Isometric Elbow Flexion Exercise.” Eur J Appl Physiol 1167–1175.

Swei Pi Wu, Chang Sheng Hsieh. 2002. “Ergonomics Study on the Handle Length and Lift Angle for The Culinary Spatula.” Applied Ergonomics 33. 493–501

Williamson A and Hoggart B. 2005. “Pain: A Review of Three Commonly Used Pain Rating Scales.” Journal of Clinical Nursing 798–804.

Table 1: The one way ANOVAs result (RULA)

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Types of Motorcycle	21.1	2.00	10.5	167	0	3.10
Motorcyclists	5.48	87.0	0.063			
Total	26.5	89.0				

Table 2.Motorcyclists percentage reporting of areas were pain is experienced

Pain rating	**Elbow**						**Wrist**						**Knee**						**Ankel**					
	M1		**M2**		**M3**		**M1**		**M2**		**M3**		**M1**		**M2**		**M3**		**M1**		**M2**		**M3**	
	L	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**
1	50	53	37	37	7	3	13	0	7	0	0	0	50	53	13	10	23	23	80	80	0	0	0	0
2	43	37	47	37	60	53	53	0	37	0	0	0	37	33	53	47	50	73	20	20	30	43	50	60
3	7	7	13	17	33	43	33	40	43	0	53	0	10	10	17	37	27	3	0	0	50	50	30	37
4	0	3	0	7	0	0	0	57	10	50	43	7	3	3	13	3	0	0	0	0	7	7	17	3
5	0	0	3	3	0	0	0	3	3	47	3	67	0	0	3	3	0	0	0	0	3	0	3	0
6	0	0	0	0	0	0	0	0	0	3	0	27	0	0	0	0	0	0	0	0	10	0	0	0

(L – Left, R- Right and M –Motorcycle)

Table 3: The two way ANOVAs (with replication) for pain rating of all 3 types of motorcycle

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Sample	128	2.00	64.2	85.2	0.000	3.01
Columns	476	7.00	68.0	90.2	0.000	2.02
Interaction	37.5	14.0	2.68	3.55	0.000	1.71
Within	524	696	0.75			
Total	1166	719				

Table 4: The one way ANOVAs result (PRS)

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	156	7.00	22.2	112	0.000	2.05
Within Groups	45.9	232	0.20			
Total	202	239				

Table 5: Tukey HSD test indicated statistically significant differences between Groups of body parts

Treatments Pair	**Tukey HSD**		
	Mean Diff	**p-value**	**Inference**
MLE vs MLW	0.89	0.001	p<0.01
MLE vs MLA	0.46	0.002	p<0.01
MLE vs MRW	2.56	0.001	p<0.01
MLW vs MLK	0.76	0.001	p<0.01
MLW vs MLA	0.43	0.004	p<0.01
MLW vs MRE	0.78	0.001	p<0.01
MLW vs MRW	1.67	0.001	p<0.01
MLW vs MRK	0.83	0.001	p<0.01
MLW vs MRA	0.70	0.001	p<0.01
MLK vs MRW	2.42	0.001	p<0.01

MLA vs MRW	2.10	0.001	p<0.01
MLA vs MRK	0.40	0.013	p<0.05
MRE vs MRW	2.44	0.001	p<0.01
MRW vs MRK	2.50	0.001	p<0.01
MRW vs MRA	2.37	0.001	p<0.01

Table 6: Tukey HSD test indicated statistically non significant differences between Groups of body parts

Treatments Pair	**Tukey HSD**		
	Mean Diff	**p-value**	**Inference**
MLE vs MLK	0.13	0.900	p>0.05
MLE vs MRE	0.11	0.900	p>0.05
MLE vs MRK	0.06	0.900	p>0.05
MLE vs MRA	0.19	0.671	p>0.05
MLK vs MLA	0.32	0.088	p>0.05
MLK vs MRE	0.02	0.900	p>0.05
MLK vs MRK	0.08	0.900	p>0.05
MLK vs MRA	0.06	0.900	p>0.05
MLA vs MRE	0.34	0.055	p>0.05
MLA vs MRA	0.27	0.284	p>0.05
MRE vs MRK	0.06	0.900	p>0.05
MRE vs MRA	0.06	0.900	p>0.05
MRK vs MRA	0.13	0.900	p>0.05

Table 7: The two way ANOVAs (without replication) for right wrist pain rating of all three types of motorcycle

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows(riders)	11.7	29.0	0.40	1.50	0.096	1.66
Columns(motorcycle)	37.1	2.00	18.5	69.0	4.6E-16	3.16
Error	15.6	58.0	0.27			

Total	64.3	89.0

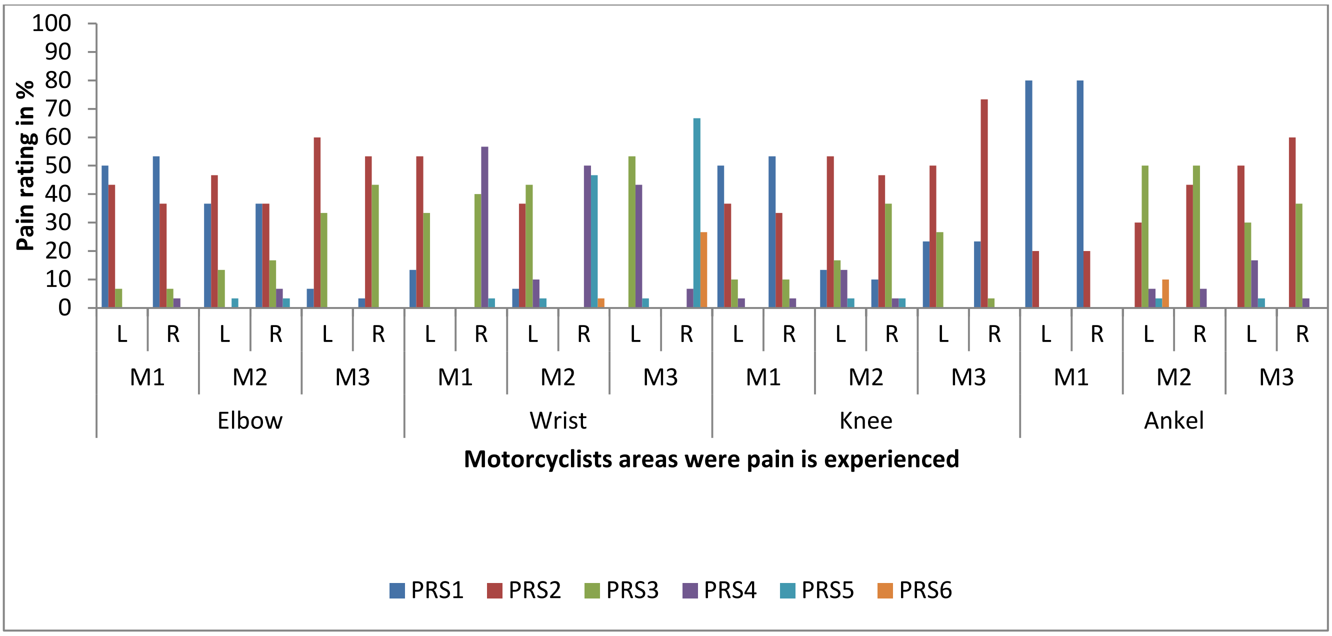
Table 8. T-Test: Two-Sample Assuming Equal Variances

	Mean score of NRS (right wrist)	*Mean score of RULA C*
Mean	4.46	4.45
Variance	0.13	0.031
Observations	30	30
Pooled Variance	0.082	
Hypothesized Mean Difference	0	
Df	58	
t Stat	0.075	
P(T<=t) one-tail	0.47	
t Critical one-tail	1.67	
P(T<=t) two-tail	0.94	
t Critical two-tail	2.00	

Figure 1. Typical motorcycle rider's static posture with various body angles

Figure 2. Typical motorcycle rider’s dynamic posture with various body angles

Figure 3. Motorcyclists percentage reporting of areas were pain is experienced



(L – Left, R- Right, M –Motorcycle and PRS – Pain rating scale)