

Contents lists available at [ScienceDirect](https://www.sciencedirect.com)

Journal of Transport & Health

journal homepage: www.elsevier.com/locate/jth

Understanding the impact of physical fatigue and postural comfort experienced during motorcycling: A systematic review



Holman Ospina-Mateus^{a,b,*}, Leonardo Augusto Quintana Jiménez^b

^a Universidad Tecnológica de Bolívar, Department of Industrial Engineering, Cartagena, Colombia

^b Pontificia Universidad Javeriana, Department of Industrial Engineering, Carrera 7 # 40-62, Bogotá, Colombia

ARTICLE INFO

Keywords:

Motorcycle
Comfort
Fatigue
Musculoskeletal disorders
Posture
Systematic review

ABSTRACT

Background: This literature review examines reports on the effects of fatigue and comfort on the motorcycle driving experience and evaluates studies of associated relevant risk factors for musculoskeletal disorders.

Methods: This systematic review of literature employed a synthetic approach using best evidence to address the question: "Does fatigue and postural comfort contribute to the development of musculoskeletal conditions and disorders presented by motorcyclists?" The initial search identified 9,024 academic articles published from 1970 to date, in 13 databases. After screening, a total of 35 articles met the criteria and were included. twelve were found to be of high quality, eighteen of medium quality, and five of low quality.

Results: In this systematic review, postural and anthropometric factors, as well as techniques and tools for the muscular analysis of motorcyclists were identified. The tools identified were classified into direct assessment techniques (anthropometry, electromyography, dynamometry, vibration evaluation, seat pressure analysis, heart rate and blood pressure, and fatigue of the pupillary muscles) and observational or indirect assessment techniques (self-reports and questionnaires). Most of the reviewed studies (83%) included evidence that physical fatigue and postural discomfort affect the performance and are related to musculoskeletal conditions; 17% (six) of the studies evaluated provided neutral evidence. The lower back was the area of the body most affected by discomfort and fatigue in motorcyclists (63% of the studies), followed by the shoulder and forearm (51% of studies). Other affected areas were the neck, and the buttocks reported by 34 to 43% of the included studies.

Conclusion: Our review shows that the different muscles affected due to motorcycle driving and the techniques used for assessment need to be comprehensively evaluated. Thus, proper selection and design of motorcycles is imperative for improving the comfort of motorcyclists.

1. Introduction

Motor vehicles have acquired a high relevance in the performance of daily activities. Motorcycles are used in utilitarian tasks in relation to mobility, transport, sports, and economic activities (by police, postmen, domiciliary workers, and dispatchers, among others) (Balasubramanian and Jagannath, 2014). Motorcycles are compact, agile, consume less fuel, and are easy to maneuver (Shafiei et al., 2015). They are cheaper and require less maintenance compared to automobiles (McInally, 2003). In spite of the above-mentioned benefits, motorcycles have been associated with a high level of risk, and are deemed to be unsafe (Shahar et al.,

* Corresponding author at: Universidad Tecnológica de Bolívar, Department of Industrial Engineering, Cartagena, Colombia.

E-mail addresses: hospina@utb.edu.co (H. Ospina-Mateus), lquin@javeriana.edu.co (L.A. Quintana Jiménez).

<https://doi.org/10.1016/j.jth.2019.02.003>

Received 29 June 2018; Received in revised form 29 January 2019; Accepted 3 February 2019

Available online 27 February 2019

2214-1405/ © 2019 Elsevier Ltd. All rights reserved.

2010). Motorcycles are unstable, and motorcycling requires adequate driving skills to control the vehicle. Driving of motorcycles is risky in relation to the level of exposure to the environment, noise, and vibrations, among other factors (Walker et al., 2006). Riding a motorcycle attracts a greater risk of a crash than does riding a car (Horswill and Helman 2003). The motorcycles contribute greatly to traffic crashes in the world (WHO, 2015).

A proper analysis of the severity of crash in motorcyclists should include factors such as road conditions, driver-related factors (human factors, age, experience, sex), and motorcycle-related factors (Haworth and Rowden 2006). This systematic review seeks to understand the relationship between the rider, the environment, and the vehicle, and to identify the factors influencing the comfort and physical fatigue of the drivers; these factors have been implicated in musculoskeletal disorders and in motorcycling-associated risks.

1.1. Fatigue and discomfort in motorcycling

Comfort is related to individual physical experiences (Hedberg, 1987). Zhang et al. (1996) established that comfort is associated with a relaxed and less stressful situation. Bodily discomfort is associated with biomechanical factors such as joint angles, postures, stresses, muscular contractions, and pressure distribution while seating. Comfort and discomfort are unique estimates in the field of ergonomics that include human perception (feedback) of the machine and the work environment (Alias et al., 2016). Comfort involves objective and subjective measurements (Bridger, 2008). Some researchers define "comfort" as a lack of discomfort. Driving comfort is important for postural and physical adjustment due to the restrictions that motorcycles present (Robertson and Porter, 1988). Comfort is associated with the absence of malaise and is an important qualitative aspect of ergonomics in the safe design of two-wheeled vehicles (Chou and Hsiao, 2005). As for the motorcyclists, comfort could be identified as symptoms of un-comfortableness in parts of the body due to the sitting posture (Kolic, 2008). In general, discomfort in the body is the first symptom of several types of musculoskeletal disorders (Gillen, 1998).

The subjective perception of the motorcyclist is manifested through elements such as demotivation and inability to maintain the desired intensity of effort or technical quality while driving (Mizuno et al., 1998a,b). Driving a motorcycle places excessive physical demands, which has an impact on physical and psychological fatigue (Dutta et al., 2014). The motorcycle can be a restricted workstation with limited adjustment capacity (Robertson, 1986). From the physiological point of view, a motorcyclist performs a monotonous task in an almost static posture affected by various physical parameters, causing rigidity and decreased blood flow in the muscles (Chou and Hsiao, 2005).

Driving fatigue is related to maintaining a specific body posture, absorbing the impact of the road, and generating the necessary forces to control the motorcycle. The mechanisms for the quantification of fatigue are varied. Analysis of fatigue experienced by motorcyclists involves the following factors: driver or motorcyclist, vehicle or machine (motorcycle), driving surroundings and environment (climatic and physical conditions of the road), length of driving experience, driving behavior, and maneuvers (Ma et al., 2003; Horberry et al., 2008). Motorcyclists are exposed to external discomfort due to the inertia of the engine, inadequacies in the structural design of the motorcycle, and varying road conditions (Cheng et al., 2011). Karmegam et al. (2009) indicated that more than 50% of motorcyclists suffer from symptoms of discomfort. Health problems such as back and finger pain, as well as shoulder afflictions, have been identified (Mirbod et al., 1997a,b). Additionally, health problems can result in a significant increase in medical costs for motorcyclists.

The purpose of this systematic review was to analyze the perceptions, anthropometric factors, postural comfort factors pertaining to motorcycling, and techniques and tools for the muscular analysis of motorcyclists. The studies that complied with an a priori design and with specific quality criteria have been evaluated in detail and their results have been extracted and synthesized. According to the synthesis of the evidence, recommendations have been made for future studies. The article is organized as follows: The method developed to perform the systematic review and considerations of selection, extraction, and synthesis of relevant articles is provided in Section 2. In Section 3, the synthesis of evidence of the selected articles is described. In Section 4, a discussion of the obtained results is presented. Conclusions and suggestions for future research are presented in Section 5. This review also aimed to identify the factors that most affect the development of musculoskeletal disorders in motorcyclists; a discussion and recommendation of the methods to prevent such disorders and associated risks in the driving of motorcycles is also presented.

2. Methods

A literature search was performed in the following stages: i) definition of the research question; ii) identification of key search terms; iii) identification of database and search strategies; iv) search scheme and article filtering; v) extraction and synthesis of relevant information; and vii) analysis of information and evidence.

2.1. Definition of research question

This review sought to determine the effect generated by the interaction of man and machine during the driving of motorcycles, and the physical impact of such an interaction, with an emphasis on the muscular activity, of the motorcyclist. The researchers raised the question: "Are physical fatigue and postural comfort factors related to the presence of musculoskeletal disorders in motorcyclists?" The research focus excluded injured caused by collision, since injuries would need to be studied based on the conditions and the causal interactions of the event.

Table 1

List of terms used for the literature search, grouped into four different types of terms.

Group	Search terms
Vehicle	Handlebar, Moped, Motorbike, Motorcycle, Motorcyclist, Rider, Scooter, Two-wheeled
Driving and Use	Anthropometry, Comfort, Discomfort, Ergonomic, Exposure, Fatigue, Physical, Posture, Seat, Stability, Static, Vibration
Conditions, Musculoskeletal disorders	Back, Disorders, Epidemiology, Forearm, Hand-arm, Low back, Lumbar, Muscle, Musculoskeletal, Pain, Risk, "Risk factor", Shoulder, Spine, Trunk

2.2. Identification of key search terms

The definition of key terms was based on words related to motorcyclists, ergonomics, and posture. The preliminary search protocol allowed us to define these terms based on keywords. The following basic terms were used for querying the title, summary, and key words: motorcycle, motorcyclist, posture, comfort - uncomfortableness, and fatigue (and different variations of this word in the English language). The preliminary search identified a set of 46 recurrent words in 250 articles, of which 34 were prioritized (See [Appendix 1](#)). The words were categorized into three groups of interest, as follows: i) Vehicle-related words: Identifying the types and names of vehicles, and the various components of the vehicles and the drivers; ii) Driving and use-related words: Indicating conditions of driving and comfort; Musculoskeletal disorder-related words: Indicating conditions of pain, afflictions, and disorders in the body, as pertaining to the musculoskeletal system. [Table 1](#) presents the 34 key terms identified in this phase of the review.

2.3. Identification of databases, strategies, and search criteria

For this study, 13 databases associated with subjects such as ergonomics, health, transport, and sports (ISI WEB OF KNOWLEDGE, PUBMED, MEDLINE, SCOPUS (ELSEVIER), SCIENCE DIRECT (ELSEVIER), EBSCOhost, EMBASE, CINAHL, SAGE, IEEE, WILEY, PROQUEST, and GOOGLE SCHOLAR) were searched. Publications from the year 1970 to April 15, 2018 were included in this review. The search strategy was developed using combinations of keywords from following three categories: vehicle, vehicle-driving and use, and musculoskeletal disorders. Scientific and academic articles in books, reports, book chapters, theses, dissertations, and conference presentations were included in the search. Words related to horse riding, horseback riding, horses, and water vehicles were excluded (the word "Rider" caused the inclusion of these unrelated results). The bibliographic search criteria are detailed in [Appendix 2](#). The search included articles reported in the references of the identified articles.

2.4. Search scheme and article selection

Methodologies adapted from Cochrane ([Higgins and Green, 2011](#)) and PRISMA (Preferred reporting items for systematic reviews) ([Moher et al., 2010](#)) were used for the selection and evaluation of articles. The results obtained from searching the different databases were merged and the duplicates were removed. The criteria were defined to establish parameters for various aspects as follows: i) Priority; ii) Relevance; iii) Impact; and iv) Quality. The details applied in the priority filter considered the most significant words were defined in two subsets that allowed a refined selection by title, summary, and keywords (See [Appendix 3](#)). The details applied in the relevance filter considered the title of the article and the full summary of the prioritized articles and the manuscripts were classified by their scope in four study segments (See [Appendix 4](#)). Using the impact filter, articles related to motorcyclist and motorcycle interactions, and including ergonomic or health-related topics such as fatigue, comfort, and posture conditions, were selected. All other articles were discarded. The impact assessment was defined after reading the entire article in relation to the following questions:

- I. Was comfort, or fatigue assessed in the drivers and their relationship with the motorcycle?
- II. Were measurements taken in focal or representative groups?
- III. Were solutions or design of applications, instruments, or methodologies developed?
- IV. Was the relationship between musculoskeletal disorders and motorcycle driving experience evaluated in the study?
- V. Were risk factors defined in relation to the development of disorders or ailments in motorcyclists?

The impact scores summarized for each article were based on a weighted score for the five questions. The articles were grouped into "Strong" (70% to 100%), "Moderate" (40% to 69%), and "Partial" (0% to 39%) impact groups. After each article was read in its entirety, quality analysis was applied to articles defined as having a "Strong Impact". A set of key criteria was defined, considering reference studies in ergonomics and other reviews assessing musculoskeletal disorders ([Brewer et al., 2006](#); [Rodríguez and Barrero, 2017](#)). The factors considered were as follows: clear definition of hypothesis, sample quality (selection, inclusion, and sample size), traceability and monitoring, definition of control groups, definition of direct and indirect evaluation methods, muscle analysis, definition of methods in descriptive analysis and statistical inference, robust evaluation of the relationship of motorcycling with musculoskeletal disorders, activity evaluated environments (not simulated, not laboratory), conclusions pertaining to the study hypotheses, discussion, depth and coverage of the investigation. Quality scores were based on a weighted score of the 12 criteria. Values ranged from "Yes" (1), "P-Incomplete" (0.5), to "No" (0). The highest possible weighted score was 28 points. For quality

synthesis, the articles were grouped into "High" (70% to 100%), "Medium" (50% to 69%), and "Low" (0% to 49%) quality groups.

2.5. Extraction and synthesis of relevant information

Relevant information was extracted, and summary tables were constructed. The items considered for evidence synthesis were as follows: general study design, hypothesis, study population, intervention or measurement type, observation or experimentation scenarios, ergonomic evaluation techniques, muscle analysis, musculoskeletal results, techniques and statistical conclusions, findings and general results, assumptions and limitations of the study, and future research possibilities. The ergonomic intervention techniques were classified as direct (electromyography, anthropometry, and vibration, among others) or indirect (questionnaires, self-reports) techniques.

For evaluating the studies, the items were characterized according to the sample groups, control groups, applied statistical techniques, and the body parts that were involved in triggering musculoskeletal disorders.

2.6. Analysis of information and evidence

The researchers used the "best evidence synthesis" approach (Slavin, 1995). This approach allowed for the assessment of the consistency of conclusions and findings among different investigations of similar quality. A study was considered as positive evidence [+] when the result demonstrated the impact of muscle fatigue and postural comfort in the development of musculoskeletal conditions. Neutral evidence [N] was defined when there was no clarity as to the relationship of musculoskeletal disorders with muscle. Negative evidence [-] was defined when the investigation did not demonstrate an impact of motorcycling on the musculoskeletal system.

3. Results

3.1. Literature search and identified studies

Using the search terms as presented in Table 1, 11,725 articles were identified in total and 2,701 duplicates were removed; the remaining 9,024 articles were consolidated (See Fig. 1). Using the priority level assessment, 8,588 articles were excluded. The remaining 436 articles were evaluated. The authors excluded 67 articles related to motorcycling or motorcyclists which dealt with subjects not pertinent to the research question, 211 articles which were related to the mechanical and physical analysis of motorcycles, and 13 articles which were related to crashes and road infractions. Finally, 144 investigations related to the interaction between motorcyclists and the motorcycle with reference to ergonomic elements were evaluated according to the items designed for the relevance category (See Appendix 5). The analysis yielded 50 articles of low, 60 of moderate, and 35 articles of strong relevance. The authors reviewed the 35 studies with strong relevance to determine quality, and to obtain a complete picture of the state of the literature.

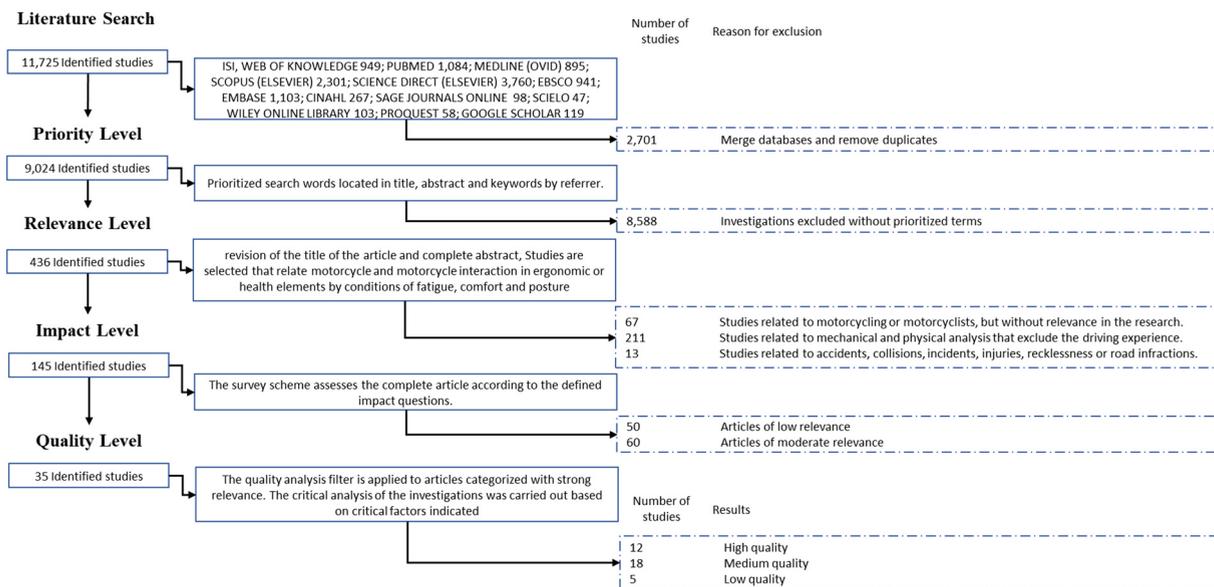


Fig. 1. Process of selection of studies for inclusion in the review. *Flowchart of the systematic review process up to data extraction with tracking of number of articles associated with each step.

Table 2
Quality assessment of the 35 selected articles and their compliance with each of the quality factors.

Authors	Defined Objectives or Hypothesis	Sample Size		Follow-Up		Control group	Direct measurement	Indirect or subjective measurement	Muscular analysis	Appropriate statistical method	Relationship with MSDs	Real-world environment (not simulated)	Consistent conclusions			Scope, coverage, and depth	Quality qualification
		3	2	1	2								3	1	2		
(Khamis et al., 2014a,b)	Y	N	N	N	Y	Y	Y	Y	N	N	N	Y	Y	Y	N	N	L
(Roseiro et al., 2016)	Y	N	N	N	N	N	Y	N	N	N	P	Y	Y	Y	Y	Y	L
(Khamis et al., 2014a,b)	Y	Y	N	N	Y	N	Y	Y	N	N	N	Y	Y	Y	P	L	L
(Jothi Prasanna et al., 2017)	Y	N	N	N	Y	N	Y	Y	N	N	N	Y	Y	Y	N	N	L
(Sai Praveen and Ray, 2009)	Y	Y	N	N	Y	N	Y	Y	N	N	N	Y	Y	Y	P	L	L
(Chou and Hsiao, 2005)	Y	Y	Y	N	Y	Y	Y	Y	N	Y	N	Y	Y	Y	Y	Y	M
(Mohamad et al., 2014)	Y	Y	N	N	Y	N	Y	Y	N	N	P	Y	Y	Y	P	M	M
(Stedmon et al., 2008a,b)	Y	N	N	N	Y	N	Y	Y	N	N	P	Y	Y	Y	Y	M	M
(Shafei et al., 2015)	Y	Y	N	N	Y	Y	N	Y	N	Y	N	Y	Y	Y	P	M	M
(Anrutkar and Rajhans 2011)	Y	Y	N	N	Y	N	Y	Y	N	N	N	Y	Y	Y	P	M	M
(Ramassamy et al., 2017)	Y	Y	N	N	Y	N	Y	Y	N	N	P	Y	Y	Y	Y	M	M
(Dutta et al., 2017)	Y	Y	N	N	Y	N	Y	Y	N	P	P	Y	Y	Y	P	M	M
(Muslim et al., 2015)	Y	P	N	N	Y	Y	Y	Y	N	Y	N	Y	Y	Y	P	M	M
(Dutta et al., 2014)	Y	Y	N	N	Y	Y	Y	Y	N	N	N	Y	Y	Y	Y	M	M
(Matsumoto et al., 1982)	Y	Y	N	N	Y	Y	Y	N	N	N	N	Y	Y	Y	Y	M	M
(Khamis et al., 2016)	Y	Y	N	N	Y	N	N	Y	N	N	Y	Y	Y	Y	Y	M	M
(Rashid et al., 2016)	Y	P	N	N	Y	N	Y	N	Y	N	P	Y	Y	Y	Y	M	M
(Mar'arof et al., 2017)	Y	P	N	N	Y	Y	Y	N	Y	N	P	P	P	P	P	M	M
(Moreno et al., 2011)	Y	P	N	N	Y	N	Y	N	N	Y	P	Y	Y	Y	Y	M	M
(Koyano et al., 2003)	Y	P	N	N	Y	Y	Y	Y	N	P	N	N	Y	Y	P	M	M
(Rashid et al., 2015)	Y	Y	N	N	Y	N	Y	Y	Y	N	N	N	Y	Y	P	M	M
(Robertson and Minter, 1996)	Y	Y	N	N	Y	Y	Y	Y	N	N	N	Y	Y	Y	Y	M	M
(Mirbod et al., 1997a,b)	Y	Y	N	N	Y	N	Y	Y	N	P	Y	Y	Y	Y	Y	M	M
(Mirbod et al., 1997a,b)	Y	Y	N	N	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	H	H
(Marina et al., 2013)	Y	Y	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	H	H

(continued on next page)

Table 2 (continued)

Authors	Defined Objectives or Hypothesis	Sample Size	Follow-Up	Control group	Direct measurement	Indirect or subjective measurement	Muscular analysis	Appropriate statistical method	Relationship with MSDs	Real-world environment (not simulated)	Consistent conclusions	Scope, coverage, and depth	Quality qualification
	3	3	2	1	2	2	3	2	3	1	3	3	
(Balasubramanian and Jagannath, 2014)	Y	Y	N	N	Y	Y	Y	Y	Y	Y	Y	Y	H
(Karuppiyah et al., 2012)	Y	Y	N	N	Y	Y	N	Y	Y	Y	Y	Y	H
(Marina et al., 2015)	Y	Y	N	Y	Y	N	Y	Y	Y	N	Y	Y	H
(Marina et al., 2011)	Y	Y	N	Y	Y	N	Y	Y	Y	N	Y	Y	H
(Karmegam et al., 2013)	Y	Y	N	N	N	Y	N	Y	Y	Y	Y	Y	H
(Velagapudi et al., 2010)	Y	P	N	N	Y	Y	Y	N	P	Y	Y	Y	H
(Torrado et al., 2015)	Y	Y	N	N	Y	N	Y	Y	P	N	Y	Y	H
(Hafzi et al., 2011)	Y	Y	N	Y	N	Y	N	Y	Y	Y	Y	Y	H
(Karmegam et al., 2009)	Y	Y	N	N	N	Y	N	Y	Y	Y	Y	Y	H
(Chen et al., 2009)	Y	Y	N	Y	Y	N	N	Y	Y	Y	Y	Y	H
% of studies complying with the factor	100%	80%	0%	29%	66%	74%	26%	47%	49%	71%	99%	80%	

MSDs, musculoskeletal disorders.

Note: Assessment of the studies: Yes (Y; Y:1), No (N; N:0), Present but Incomplete (P: P:0.5). Quality: High (H), Medium (M), and Low (L). The highest possible weighted score was 28 points.

3.2. Quality assessment of studies

The quality evaluation of the 35 studies is presented in [Table 2](#). While twelve articles were of high quality, eighteen were of medium quality, and five of low quality. The main aspect that affected the quality of the studies was the lack of follow-up, and none of the studies evaluated satisfied this quality condition. A muscular analysis of the motorcyclists was conducted in 26% (nine) of the studies. Control groups were defined in 10 articles (29%), and a clear methodology for statistical analysis of data was described in 47% (16) of the studies. An analysis of the presence or development of musculoskeletal disorders was reported by 50% of the studies. Of the various ergonomic measurement techniques, 66% of studies (23) performed direct measurements, while 74% (26) performed indirect measurements. Of the evaluated studies, 26 studies are developed in real environments. In 80% of the selected studies (28) the sample size was greater than 10 participants, and 80% of the studies analyzed, developed, and formulated their research with the required coverage and scope. Low-quality studies described conditions and ailments unrelated to the musculoskeletal system; such studies did not perform a muscular analysis of the motorcyclists. High-quality studies included an evaluation of musculoskeletal conditions and muscle analysis, and in addition, performed appropriate statistical analysis of these parameters. The studies assessed to be of average quality in their majority did not involve muscular analysis but included an evaluation of musculoskeletal ailments of the motorcyclists. The article quality rating was compared to the quality rating of the journal (Quartile-SJR) and the quality status was retained (P-value:0.323) (see [Appendix 6](#)).

3.3. Data extraction and evidence synthesis

Evidence that physical fatigue and postural uncomfortableness affect the performance of motorcyclists and are related to musculoskeletal conditions and ailments, was included in 83% of the studies. Based on the scope, time, or follow-up of the study, neutral evidence was presented in 17% of the studies evaluated (six). Of the studies with neutral evidence, one was a high-quality study, four were medium-quality, and one was a low-quality study. No study denied the effects of postural and physical factors on fatigue and uncomfortableness in motorcyclists. Methodological characteristics of the 35 articles selected by scope, type, sample population, and study region are shown in [Table 3](#). Of the studies analyzed, there were four studies conducted between 1980 and 2000, seven investigations between 2001 and 2010, and 24 studies conducted between 2011 and 2017.

The selected studies included a total of 105 authors. The studies were from the following countries: Malaysia (n = 12), India (n = 8), Spain and Japan (n = 4), Taiwan and the United Kingdom (n = 2), and Colombia, Indonesia, and Portugal (n = 1 each). The Asian continent was the origin of 27 investigations, Europe of seven, and America of one investigation. According to the design of the study in the articles evaluated, field research was conducted in 69% (24) of the studies, and laboratory research was conducted in 31% (11) of the studies. Only 23% (eight) of the studies were randomized in their design and execution. [Fig. 2](#) shows in detail the design types and quality of the included studies.

From the perspective of sample size, only 29% (10) of the studies included control groups (six high-quality and four medium-quality studies). A summary of the characteristics of the study populations such as the sample size, control group, age, sex, average, experience, professional role, weight, and height are summarized in [Appendix 7](#).

It was noted that 47% of the investigations made use of statistical methods. The most common analysis techniques were descriptive and inferential statistical analyses, with 66% and 40% incidence, respectively. While 18 studies used more than two statistical analysis techniques, nine studies did not indicate the statistical techniques used. Five studies used regressive methods or prediction functions of the measured variables, and 26% of studies implemented the ANOVA technique. All the selected articles demonstrated within their objectives or research context the desire to assess factors of physical fatigue or physical discomfort by evaluating motorcycle drivers with direct (dynamometry, anthropometry, blood pressure, electromyography, vibrations, among others), or indirect (subjective, questionnaire or self-report, software's, among others) ergonomic measurement techniques. [Table 3](#) specifies the article characteristics pertaining to the methodologies and techniques implemented, and findings published.

3.4. Methodologies and techniques implemented in the studies

In this section, the measurement techniques evidenced in the evaluated studies are described. In [Appendix 8](#) the relationship of these techniques is summarized.

3.4.1. Anthropometry

Five of the evaluated studies were focused on the development of anthropometric measurements. All five studies were of medium quality; four of these studies reported positive evidence ([Robertson and Minter, 1996](#); [Chou and Hsiao 2005](#); [Stedmon et al., 2008a,b](#); [Amrutkar and Rajhans, 2011](#); [Dutta et al., 2014](#)). The study by [Robertson and Minter \(1996\)](#) was defined as neutral evidence because it did not directly evaluate postural uncomfortableness. In studies with anthropometry, the average sample size was 60 people with an average age of 28 years. Taiwan, India, and the United Kingdom were the countries in which these studies were conducted. Three studies evaluated both men and women, while two studies only focused on the men. Some of the most significant findings are presented below.

[Robertson and Minter \(1996\)](#) found that the motorcyclist population showed a significantly higher body height than did the general population. [Chou and Hsiao \(2005\)](#) considered the length of the body segment from the angles formed in the driving position and finally determined a methodology for the design of a scooter. [Stedmon et al. \(2008a,b\)](#) identified that perceived comfort changes in the same individual according to the type of motorcycle. [Amrutkar and Rajhans \(2011\)](#) determined that motorcycles designed with

Table 3
General and methodological characteristics and findings of the studies selected in this review.

Study (quality: evidence) (design)	Country	Objective-hypothesis-research context-data	Population (Sample size)	Measures	Findings and results
(Chou and Hsiao, 2005) [M: +1] (FNR)	Taiwan	Methodology to record the body segment length and position of individuals who use scooters.	30 male and 30 female university or graduate students. Age 18–25 years. Riding experience of more than 1 year. Height 167.3 (SD 7.67) cm.	Anthropometry; Questionnaire; Real-field measurement.	Wrist and lower back were commonly identified as the body parts with perceived discomfort because these were considered as the major body parts involved in maintaining riding stability while driving a two-wheeled vehicle. The study showed that the motorcyclists usually experienced body discomfort at lower back, upper back, wrist, buttocks, and neck areas.
(Mohamad et al., 2014) [M: +1] (FNR)	Malaysia	Identify the body parts where discomfort is localized in motorcyclists and understand the vibration exposure effect on different road types.	100 male motorcyclists consisting of postmen, fast food deliverymen, and dispatch personnel. Age 30 (SD 5.92) years, experience 14 (4.90 SD) years. Including two male participants (Vibration) with a body weights outside of the study weight range, 45–65 kg and > 70 kg.	Vibration measurement; Questionnaire; Real-field measurement.	
(Mirbod et al., 1997a,b) [H: +1] (FNR)	Japan	Evaluate subjective symptoms in the fingers, arms, and shoulders of a group of motorcycling traffic policemen in comparison with those of a control group without occupational vibration exposure.	119 motorcycling traffic policemen and 49 male control participants. 4 participants randomly selected for the measurement of vibration exposure. Age 38 (SD 7.4) years. The control group was aged 37 (SD 6.7) years. Experience 8 (SD 4.8) years. The average daily time of motorcycling 6 (SD 0.8) h/day.	Vibration measurement; Questionnaire; Real-field measurement.	The prevalence of various subjective symptoms in the fingers, hands, or arms (shoulder) among motorcycling policemen.
(Khamis et al., 2014a,b) [L: +1] (FR)	Malaysia	Evaluate the whole-body vibration exposure value experienced by the motorcyclist under different road profiles and speeds.	Two male senior undergraduate students. Aged 22 years. At least 3 years of experience (engine size of 125 cc, two-stroke).	Vibration measurement; Questionnaire; Real-field measurement.	A slight discomfort in the back, buttocks, and hands reported; discomfort increased with the ruggedness of the terrain.
(Marina et al., 2013) [H: +1] (LNR)	Spain	Examine the forearm muscle fatigue patterns produced during two protocols (intermittent and continuous), comparing riders with a control group, and relating maximal voluntary contraction with electromyography parameters.	20 riders and 39 controls. Riders: Age 28 (SD 7.5) years; Weight 73 (SD 3.8) kg; Height 175 (SD 6.8) m. Controls: Age 25 (SD 3.8) years; Weight 71 (SD 5.7) kg; Height 175 (SD 5.3) cm. All men.	Dynamometry; Electromyography; Questionnaire; Laboratory measurements.	Effects on the carpi radialis (CR) revealed more differences among protocols and groups compared to those on the flexor digitorum superficialis (FS). The greater CR activation in riders could be interpreted as a neuromotor strategy to improve braking precision. When FS fatigue increased, the control group progressively shifted toward a bigger CR activation, adopting an intermuscular activation pattern closer to that of the riders.

(continued on next page)

Table 3 (continued)

Study (quality: evidence) (design)	Country	Objective-hypothesis-research context-data	Population (Sample size)	Measures	Findings and results
(Balasubramanian and Jagannath, 2014) [H: +] (FNR)	India	Detect physical fatigue due to motorcycle riding for an hour using surface electromyography, seat interface pressure, heart rate, and blood pressure measurements.	20 healthy male participants (free from low back pain). Age 23 (SD 3.5) years. Weight 68 (SD 10.1) kg. Height 175 (SD 0.06) cm. Experience 2 years.	Electromyography; Seat pressure analysis; Heart rate and blood pressure analysis; Questionnaire; Real-field measurement.	The participants reported significant physical fatigue in the trapezius medial, latissimus dorsi, and erector spinae muscles. Seat pressure distribution was found to be non-uniform during motorcycling. Results of a subjective evaluation on perceived discomfort showed that participants reported the highest pain score in the buttocks region.
(Stedmon et al., 2008a,b) [M: +] (LR)	UK	A quasi-experiment was designed in which 5 participants with different anthropometric characteristics rode 8 different motorcycles.	Five participants (4 male and 1 female participant(s)). Age 39 (30–46) (SD 6.3) years. Experience 10 years with an average riding time of 8 h/week, and 9,900 miles/year.	Anthropometry; Questionnaire; Real-field measurement.	The body part discomfort ratings supported a general trend as reported by Stedmon (2007) where the wrists, lower arms, neck, and buttocks were affected by riding.
(Shafiei et al., 2015) [M: +] (FNR)	Malaysia	Evaluate the effectiveness of a new model of motorcycle seat with lumbar support, aimed at reducing muscle discomfort among male motorcyclists.	94 male students; 47 subjects each in the control and experimental groups. Drivers: Age 28 (SD 7.5) years; Weight 73 (SD 3.8) kg; Height 176 (SD 6.8) cm. Controls: Age 25 (SD 3.8) years; Weight 71 (SD 5.7) kg; Height 175 (SD 5.3) cm. Experience 1 year.	Questionnaire; Laboratory measurement.	Discomfort in the neck, shoulder, upper back, arms, and the lower back.
(Amrutkar and Rajhans 2011) [M: +] (FNR)	India	Evaluate all the body dimensions concerned with motorcycle riding to estimate an ergonomic riding posture.	70 male motorcyclists, mostly college students; Age 18–25 years.	Anthropometry; Questionnaire; Real-field measurement.	The results also indicated that the motorcyclist mainly experienced discomfort in their upper body parts (neck or head, shoulder, upper back, arm and hand, low back and buttock)
(Ramasmay et al., 2017) [M: +] (LNR)	India	Investigate the risk factors of driving-related Musculoskeletal Disorders (MSD) using Quick Exposure Check (QEC).	286 male participants; Age 18 to 60 years. Experience approximately 1 hour/day or more on roads with varying quality.	Questionnaire; Real-field measurement.	Back and shoulder/arm were the most common sites for the occurrence of driving-related MSD.
(Karupiah et al., 2012) [H: +] (FR)	Malaysia	A cross-sectional study with the objective of evaluating the severity of the motorcyclist's discomfort (perceived in various areas of the body) during a prolonged riding process with and without a lumbar support.	100 student motorcyclists in good physical condition and without MSD. 50 male and 50 female students. Age 21 years. Height 165 cm. Weight 57 kg. Experience 5 years.	Questionnaire; Laboratory measurement.	Participants identified lower back and upper back as the most commonly affected body parts, prior to changes made to increase riding comfort during the testing period.
(Dutta et al., 2017) [M: +] (FNR)	India	Quantify postural and psychosocial stress that may be contributory factors to crashes, injury and record the magnitude of aggression, sensation level, and risky behavior to employ behavior-based safety measures.	150 healthy adult male motorbike riders. Age 26 years (SD 2.64). Experience 4 years (SD 1.67). Perception of riders with respect to their safety was recorded among bike riders (n = 35).	Videography and photography methods; Questionnaire; Real-field measurement.	Drivers experienced pain in the lower back, thighs, hands, neck, hips, knees, and shoulders. Riders perceived the exertion as hard and heavy. Majority of the riders preferred looks and style, neglecting physical comfort and safety. The magnitudes of aggression, sensation, and risky behavior among bike riders were notably high.
(Muslim et al., 2015) [M: N] (LR)	Indonesia	Measure the effect of cognitive, physiological, and subjective approaches towards fatigue, and determine the differences in the level of fatigue in the studied age categories.	12 male drivers in two age groups: productive age category, 16–35 years; and adult age category, 35–60 years.	Heart rate and blood pressure (systole and diastole) measurement; Questionnaire; Real-field measurement.	The influence of motorcycling on heart rate and level of fatigue was significant in both age categories (productive and adult age category).

(continued on next page)

Table 3 (continued)

Study (quality: evidence) (design)	Country	Objective-hypothesis-research context-data	Population (Sample size)	Measures	Findings and results
(Marina et al., 2015) [H: +] (FNR)	Spain	Assess the maximal voluntary contraction and time course parameters of contraction and relaxation and explore the hypothesis that force fatigue can be best modeled by a non-linear function for the majority of motorcycle riders. Analyze the exposure level of cross-motorcycle and of cycling drivers to hand-arm vibration (HAV) and to whole-body vibration (WBV). This study aimed to quantify various stressors associated with motorcycle driving.	40 male road-racing motorcycle riders. Age 28 (SD 6.8) years. Height 176 (SD 6.6) cm. Weight 72 (SD 7.4) kg. Experience 6 years.	Dynamometry; Electromyography; Laboratory measurement.	Fatigue in forearm muscles may be critical for motorcycle riders in relation to performance and to the development of forearm disorders.
(Roseiro, et al., 2016) [L: +] (FNR)	Portugal	Motorcycle the exposure level of cross-motorcycle and of cycling drivers to hand-arm vibration (HAV) and to whole-body vibration (WBV).	Six sport professional male drivers and volunteers. Age 24 (15 -18) years; Weight 73 kg. Height 170 (SD 7.6) cm; Weight: 60 (SD 4.7) kg.	Vibration measurement; Real-field measurement.	With reference to HAV, the most affected joints were the shoulder, forearm, and arm joints.
(Dutta, et al., 2014) [M: +] (FNR)	India	This study aimed to quantify various stressors associated with motorcycle driving.	10 male participants each in control and test groups, with comparable profiles; evaluation of riding a scooter. 10 male car drivers and 10 male sedentary people as control subjects. Age 20–30 years.	Anthropometry; Goniometry; Segmental exposure (handheld vibration meter) measurement; Fusion threshold measurement; Heart rate measurement; Questionnaire and Posture analysis tool software (RULA, REBA) analysis; Real-field measurement.	Results reported were as follows: Angular deviations in the lumbar region (L1–L5). Deviations in joint angles at shoulder, wrist, hip, knee, and ankle. Whole-body vibration was noted but lower back and arm were observed to experience the maximum vibration.
(Matsumoto, et al., 1982) [M: +] (FNR)	Japan	Physical examinations of peripheral circulation and vibratory sensation were undertaken in 120 postal workers.	100 male motorcycle-riders and 20 bicycle riders (controls). The motorcycle riders were divided into three groups, as follows: 29 with waxy whiteness, 51 with subjective complaints, and 20 without any complaints. Age 37 years. Experience 13 years.	Skin temperature of the finger; Nail press test; Vibratory sense threshold measurement; Real-field measurement.	The disruption in peripheral circulation and vibratory sensations were severe in the group with waxy white changes in the fingers.
(Marina et al., 2011) [H: +] (FNR)	Spain	Study the subjective fatigue in their arms and forearms experienced by motorcycle riders, by electromyography and maximal voluntary contraction patterns.	10 adult riders volunteered to participate in this study. Age 33 (SD 5.5) years. All the participants took part in a 24 h race.	Dynamometric and Electromyography measurement; Real-field measurement.	The Right Flexor muscle was reported to be affected. These results suggest fatigue is produced in motorcycle riders. The central nervous system is not the source of the forearm fatigue, and therefore is able to send the proper neural action potential.
(Khamis, et al., 2016) [M: +] (FNR)	Malaysia	Determine the prevalence of riding symptoms and their association with whole body vibration and other associated factors among motorcycle deliveryman in Malaysia.	100 males. Age 30 years. They included 90 postmen, eight food deliverymen, and two dispatch personnel.	Questionnaire; Real-field measurement.	Majority of the respondents frequently felt discomfort at the lower back, upper back, wrist, upper arm, buttock, and neck regions.
(Karmegam et al., 2013) [H: +] (LNR)	Malaysia	The relationship between discomfort in the motorcyclist's body parts while driving the motorcycle and factors such as body mass index (BMI), riding experience, riding hours, and preferred riding posture.	481 male and 476 female participants. Age 21 (18 – 24) years. Height: 163 cm. Weight: 57 kg. Experience 5 years.	Questionnaire; Laboratory measurement.	Male motorcyclists experienced discomfort symptoms in the upper back, arms/hands, and lower back. Female motorcyclists experienced discomfort throughout the body including lower body, buttocks, and upper body.
(Rashid et al., 2016) [M: +] (LNR)	Malaysia	Pilot testing and simulation setup of motorcyclists' prolonged riding activity using an indoor motorcycle simulator facility.	Five healthy male respondents. Age 23 years. Experience 1 year.	Surface electromyography (sEMG); Laboratory measurement.	Three muscle groups (erector spinae, trapezius, and extensor carpi radialis) were the most fatigued body regions as reported by the participants after a two-hour simulation.

(continued on next page)

Table 3 (continued)

Study (quality: evidence) (design)	Country	Objective-hypothesis-research context-data	Population (Sample size)	Measures	Findings and results
(Velagapudi et al., 2010) [H: +] (FNR)	India	Determine physical fatigue due to motorcycle riding using surface electromyography. Two motorcycles similar in all specifications except the riding posture were taken up for this study; one vehicle was driven while in an erect/straight posture while the other was driven in a leaning-forward posture. Measure the muscular activities (RMS values) of various motorcycling postures as follows: (i) forward-lean, (ii) upright-sitting, and (iii) neutral-sitting (as control).	Eight healthy males. Age: 35 (SD 7.8) years. Height 171 (SD 0.046) cm. Of these, six were expert riders with at least 3 years of experience in testing motorcycles. The remaining two were normal motorcycle users. All riders were right-handed.	Surface electromyography (sEMG); Questionnaire; Real-field measurement.	The forearm, mid-back, and lower back muscles of the riders were fatigued while riding the motorcycle. The EMG results showed that an upright posture caused higher fatigue than did a leaning-forward posture on rural roads (shoulder/neck; mid-back and lower back muscle groups). The upright sitting posture required high muscular activity. This study conclusively proved that any type of discomfort associated with the forward-lean posture does not originate from muscular activities, and that posture effects comfort and driver fatigue levels. Presence of central fatigue on the exerted and contralateral extensor digitorum communis.
(Ma'arof et al., 2017) [M: +] (LNR)	Malaysia	Understanding of mechanisms of fatigue induced by an intermittent fatigue protocol specifically designed for motorcycle riders.	Four male students. Age 24 (18 – 25) years. Normal BMI, ranging between 19 and 25. Subjects were healthy prior to and during the experiment. Experience 1 year. Height 171 cm. Weight 63 kg.	Surface electromyography (sEMG); Laboratory measurement.	"The results show that newer motorcycles allow 36.3% more riding time than do older motorcycles before the EAV is reached. Motorcycles with larger engine size (125 cc) allow 22.5% more riding time than do motorcycles with a smaller engine size. It is possible to ride for 44% more time on faster roads than on slow roads. Findings indicate that poor road design was the primary contributor to fatigue, whereas driving early in the morning was the least contributor.
(Torrado et al., 2015) [H: +] (LNR)	Spain	Systematic experimental design to study any statistically significant effects of rider weight, road type, engine size, and motorcycle age, on the Exposure Action time Value (EAV).	12 male participants. Age 31 years. Weight 73 kg. Height 176 cm. All subjects practiced a sport for at least 4 h per week and frequently used a motorcycle of engine size superior to 600 cc. None suffered from neuromuscular disorders.	Dynamometry; Electromyography; Laboratory measurement.	Lower back pain (LBP) was the most reported symptom; 12-month prevalence rates were 82.3% and 62.8% in OMCs and NMCs, respectively. Riding time, posture score, smoking status, and past crashes were the major factors significantly associated with higher LBP prevalence in motorcyclists.
(Moreno et al., 2011) [M: N] (FR)	Colombia	Discover the general perceptions on fatigue risk factors of teenage motorcycle riders based on the Motorcycling Fatigue Model and other practices in existing empirical studies.	Four male participants. Weight of 712 N (SD: 94.7 N). Two of the riders were heavier than 686 N (Rider 1 = 813 N, Rider 2 = 774 N), whereas the other two riders were lighter than 686 N (Rider 3 = 627 N, Rider 4 = 637 N). Each motorcycle rider had at least 4 years of experience.	Vibration measurement; Real-field measurement.	(continued on next page)
(Khamis et al., 2014a,b) [L: N] (LNR)	Malaysia	A cross-sectional study was conducted to explore the prevalence and risk factors of MSDs among non-occupational motorcyclists (NMGs) and occupational motorcyclists (OMCs).	60 teenage students. In this study, participants had a history of habitually riding various types of motorcycles as their main transportation from and to their homes and offices. 606 male and 86 female participants. 884 respondents; NMGs (N = 422) and OMCs (N = 270) including mail deliverymen (N = 189), dispatch boys (N = 53), and traffic enforcement officers (N = 82). Two groups were included, namely, non-occupational and occupational motorcyclists. Age 29 (SD 7.31) years.	Questionnaire; Real-field measurement.	
(Hafzi et al., 2011) [H: +] (FR)	Malaysia				

Table 3 (continued)

Study (quality: evidence) (design)	Country	Objective-hypothesis-research context-data	Population (Sample size)	Measures	Findings and results
(Jothi Prasanna et al., 2017) [L: +] (FNR)	India	Determine the prevalence of musculoskeletal disorders among non-occupational motorcyclists.	100 males and female subjects. Age 20–35 years. Non-occupational motor cyclists with a driving experience of above 1 year and driving duration of 2 hours/day. Exclusion criteria included a history of traumatic episodes, deformities, fractures, surgery of orthopedic or neurological nature in the past 12 months.	Questionnaire; Real-field measurement.	The study concluded that the lower back (65%), neck (57%), and wrist (31%) were the most common sites of musculoskeletal disorders among non-occupational motorcyclists in the past 12 months.
(Koyano et al., 2003) [L: N] (FNR)	Japan	A posterior characteristic index was established to quantitatively evaluate the static seating comfort of motorcycle seats. The index expresses characteristics such as the shape and size of the posterior as well as the weight of a person.	15 male and 15 female participants were selected as test subjects based on a typical body weight distribution. Seven motorcycles and five subjects were used in the test.	Seat pressure analysis; Questionnaire; Laboratory measurement.	The contact surface area and level of surface area causes changes in the body pressure distribution; data obtained while the test subject was seated were effective indices for static seating comfort and were applicable to all test subjects (buttock and thigh regions). Discomfort reported mostly in the torso body regions as follows: head and neck, shoulder and arms, wrists and hands, and upper and lower back. Only two lower extremity body regions were rated for having high discomfort, which were the buttocks, ankles, and feet.
(Rashid et al., 2015) [M: +] (LNR)	Malaysia	Identify muscle groups related to motorcycling activity, and those which may lead to motorcyclist muscle fatigue, especially during prolonged riding.	50 male students. Eight healthy male respondents participated in the electromyography analysis. Age 25 (SD 3.09) years. Height 170 (SD 0.027) cm. Weight 74 (SD 18.9) kg. Motorcycle users with at least 2 years of experience. No history of severe motorcycle crashes.	Surface electromyography (sEMG); Questionnaire; Laboratory measurement	The sitting position study indicated that there was considerable variation in the location of the most forward position of the leg of the motorcycle riders in the normal sitting position on a static test rig. The results also suggested that the location of the buttocks on the seat was relatively fixed and that the location of the knee as measured on the test rig was strongly related to the buttock-knee length.
(Robertson and Minter, 1996) [M: N] (LNR)	UK	Provide an indication of the physical dimensions of motorcycle riders which are relevant to the design of motorcycles	109 male and 31 female participants. All subjects rode motorcycles. Age 33 years. Experience 10.45 years. Weight 79 kg. Height 174 cm.	Anthropometry; Questionnaire; Laboratory measurement	The results of the discomfort survey show that majority of users perceived discomfort in parts of their upper body, especially the neck, back, buttocks, wrists, and shoulders. Lower back and buttocks were the critical areas where the discomfort perceived was significantly higher than that perceived in other areas of the body. The results of the discomfort survey showed that more than 95% of the users perceived discomfort in the body. In this study, 87% of users reported discomfort in the lower back region.
(Sai Praveen and Ray, 2009) [L: +] (FNR)	India	Understand the usage patterns and estimate the discomfort due to motorcycle usage across different segments of motorcycles.	178 male motorcycle users volunteered to participate in the study. Age 31 (SD 6.6) years; Height 173 (SD 8.89) cm. Weight 73 (SD 11.3) kg.	Questionnaire; Real field measurement.	The results of the discomfort survey show that majority of users perceived discomfort in parts of their upper body, especially the neck, back, buttocks, wrists, and shoulders. Lower back and buttocks were the critical areas where the discomfort perceived was significantly higher than that perceived in other areas of the body. The results of the discomfort survey showed that more than 95% of the users perceived discomfort in the body. In this study, 87% of users reported discomfort in the lower back region.

(continued on next page)

Table 3 (continued)

Study (quality: evidence (design))	Country	Objective-hypothesis-research context-data	Population (Sample size)	Measures	Findings and results
(Karmegam et al., 2009) [H: +] (FNR)	Malaysia	Determine the overall discomfort score to identify discomfort symptoms in various body parts; additionally, to identify the statistically significant differences in discomfort scores among male and female motorcyclists.	481 male and 476 female participants. Age 18 to 24 years. Height 163 cm. Weight 57 kg. The riding experience for male motorcyclists was of 6 (SD 2.45) years. The riding experience for female motorcyclists also ranged from 1 to 10 years, with a mean of 5 (SD 2.68) years.	Questionnaire; Real-field measurement.	The results indicated that male and female motorcyclists experienced a similar set of discomfort symptoms while riding the vehicles. The results also indicated that the motorcyclists experienced discomfort mainly in their upper body parts (neck or head, shoulder, upper back, arm and hand, lower back, and buttocks); the majority of participants reported no discomfort in their lower body parts (knee, calf, leg below knee, ankles, and feet). Shoulder stiffness and lower back pain were frequently encountered. Overall, the prevalence of subjective symptoms was higher among policemen who were currently driving motorcycles, even though they were younger.
(Mirbod et al., 1997a,b) [M: +] (FNR)	Japan	Investigate the prevalence of subjective symptoms among current and former motorcycling policemen.	46 traffic policemen currently riding motorcycles (21–48 years), and 72 traffic police officers (29–51 years) with experience of riding police motorcycles. Age 21 Years. Experience 8 years.	Questionnaire; Real-field measurement.	The impact of WBV exposure on the health of motorcycle riders should be carefully addressed with reference to ISO 2631-1 and ISO 2631-5. Most motorcycle riders do not expose themselves to WBV for extended periods. However, the increase in population and gradually aging societies imply that many motorcycle riders require special attention to screen for potential health problems resulting from WBV exposure.
(Chen et al., 2009) [H: N] (FR)	Taiwan	Compare a measured WBV exposure with the upper boundary of the health guidance caution zone as recommended by ISO 2631-1; the limit value to be associated with a high probability of adverse health effects as recommended by ISO 2631-5.	12 male students. Age 22 years (SD 1.5). Five experienced sedan drivers, with a mean age of 29 years (SD .4) were also recruited for driving tests. Height 171 cm (SD 4.3). Weight 68 kg (SD 8.6). Each motorcycle driver had at least 2 years of motorcycle riding experience.	Vibration measurement; Real-field measurement.	

Note:

Quality evaluation: H (High), M (Medium), L (Low); and Direction of Evidence: [+] positive, [-] negative, ['N'] inconclusive. Study Design: FNR (Field not Randomized), FR (Field Randomized), LNR (Laboratory Not Randomized), LR (Laboratory Randomized)
 b Age, Height, Weight reported as Mean (standard deviation (SD)).

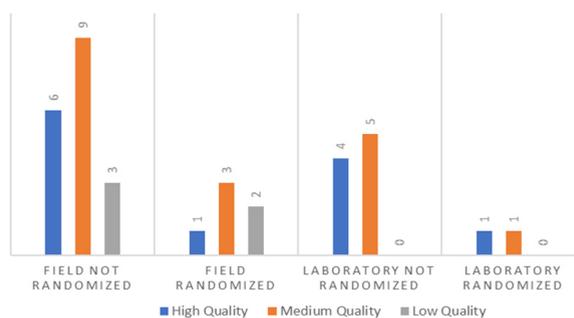


Fig. 2. Design of the study vs. quality.

American anthropometric dimensions were not comfortable for the Indian population. Using anthropometric and goniometric records, Dutta et al. (2014) identified significant deviations in the angles of the joints in the shoulder, wrist, hip, knee, and ankle in different driving postures.

3.4.2. Dynamometry

Four studies included stress measurements in arms, as evaluated using dynamometry, and were categorized as positive evidence (Marina et al. (2011, 2013, 2015); Torrado et al., 2015). The average sample size of these studies was 30 individuals and the average age was 30 years. The studies were evaluated in the laboratory with Spanish sportsmen. The assessment of effort was conducted in the hands, with the purpose of simulating the behavior while using the controls on a motorcycle (Clutch / Brake). Some of the most significant findings are presented below.

Marina et al. (2011, 2013) developed a protocol for the evaluation of muscular activity. The motorcyclists exerted a force against the brake lever (right hand), which was evaluated using the parameters maximum voluntary contraction (MVC) and sub-maximum voluntary contraction. The effort exerted decreased in the forearm in motorcyclists. Marina et al. (2015) examined force-time parameters to better characterize the reduction in maximum force generation capacity. The parameters considered were the MVC, contraction time (CT), half relaxation time (HRT), and relaxation rate (RR). The results confirmed that fatigue caused a 40% decrease in the normalized MVC compared to the baseline value; additionally, the contraction time was also increased compared to the baseline value. Torrado et al. (2015) examined the temporary course of recovery of the MVC actuated in the brake and clutch levers (right and left respectively). The results indicated that the MVC of the exercised limb did not recover to the baseline values.

3.4.3. Electromyography

Eight studies used electromyography, and all these studies presented with positive evidence (Velagapudi et al., 2010; Marina et al., (2011, 2013); Balasubramanian and Jagannath 2014; Rashid et al. (2015, 2016); Torrado et al., 2015; Ma'arof et al., 2017). Five studies were rated as high quality and three as medium quality evidence. The sample included 21 men; the average age was 28 years. The study regions were India, Malaysia, and Spain. Some of the most significant findings are presented below.

Marina et al. (2011) applied surface electromyography measurements on the finger flexors and flexor digitorum superficialis using the root mean square (RMS), mean potential (MP), median frequency (MF), and mean power frequency (MPF). The researchers identified that during sub-maximal effort (50% MVC), the mean amplitude increased, while the median and the average frequencies tended to decrease. Marina et al. (2013) assessed the amplitude (RMS) and mean frequency (MF) of the flexor digitorum superficialis (FS) and carpi radialis (CR). The researchers reported differences in the increase of RMS and the decrease of MF among the two evaluated muscles groups. The study confirmed the importance of assessing muscle groups because braking requires precision and a fine adjustment. Balasubramanian and Jagannath (2014) detect physical fatigue in muscle groups including the extensor carpi radialis (ECR), biceps brachii (BB), medial trapezius (TM), sternocleidomastoid (S), latissimus dorsi (LD), and the erector spinae (ES), in a controlled environment. The muscle groups were chosen based on preliminary studies of driving, signal strength, and accessibility. Velagapudi et al. (2010) performed the MPF and RMS amplitude measurements in four muscle groups (flexor carpi ulnaris, trapezius, latissimus dorsi, and erector spinae). The results showed muscle fatigue in these muscle groups. Rashid et al. (2015) performed a pilot experiment in muscle groups including the erector spinae, latissimus dorsi, trapezius, triceps, and the carpi radialis extensor. The results showed signs of muscular activity in these muscle groups, and the activity was strong especially in the extensor carpi radialis muscle. Rashid et al. (2016) and Ma'arof et al. (2017) performed measurements of bilateral muscle activity in the erector spinae (lower back), latissimus dorsi (middle back), extensor carpi radialis (forearm and wrist), and trapezius (shoulder) muscles using the RMS and the MPF parameters. The results showed the presence of fatigue in the muscle groups and that the motorcyclist's forward stance led to lower readings compared to those of all the selected muscles. Meanwhile, the upright motorcycling posture resulted in a much higher value of muscle activity.

3.4.4. Vibration measurement

In eight prior studies, vibration measurements were performed using an accelerometer (Matsumoto et al., 1982; Mirbod et al., 1997a,b; Chen et al., 2009; Moreno et al., 2011; Dutta et al., 2014; Khamis et al., 2014a,b; Mohamad et al., 2014; Roseiro et al., 2016). Two articles were rated as high quality, four of medium quality, and two of low quality. According to the evidence, only two

articles presented neutral evidence. The average sample size was 53 motorcyclists and the average age was 28 years. All the motorcyclists were men. The human exposure to vibrations is classified according to characteristics, as whole-body vibration (WBV) and hand-arm vibration (HAV). Some of the most significant findings are presented below.

Matsumoto et al. (1982, 1986) studied the exposure of motorcyclists to HAV and reported that acceleration levels in the handlebars of motorcycles traveling on paved roads exceeded the ISO exposure guidelines. In addition, they determined that the vibration load of a motorcycle handle on the right side was higher than that on the left side due to the structure of the motorcycle and the way it is operated. Chen et al. (2009) developed an analysis of WBV exposure experienced by motorcycle riders. The measurements were made in the seat of the motorcycle. Root mean square (RMS) acceleration, vibration dose value (VDV), and daily static compression dose (Sed) were determined from the collected data in accordance with the ISO 2631-1 and ISO 2631-5 standards. Moreno et al. (2011) determined the main effects caused in the limits of exposure to body vibration considering the age of the motorcycle, engine size, type of road, and weight of the driver. The results showed that newer motorcycles allowed 36.3% more driving time than did older motorcycles before the exposure action value (EAV) time was reached. Mohamad et al. (2014) performed measurements of HAV of motorcyclists on two types of roads using an accelerometer on the right handlebar of the motorcycle; the results showed that different road types influence the vibration exposure of the motorcyclist. Khamis et al. (2014a,b) evaluated the WBV exposure value experienced by the motorcyclist under different motorcycle speeds and road profiles. Roseiro et al. (2016) analyzed the HAV and WBV exposure level of cross motorcycle drivers and cycling drivers. Researchers concluded that motorcyclists were exposed to levels of effective acceleration that were higher than the action value recommended by the ISO-5349e1-I (2001) for HAV exposure and that recommended by the ISO-2631e1-I (1997) for WBV exposure.

3.4.5. Other direct measurements

Other measures included heart rate and blood pressure (systole and diastole) analyses (Balasubramanian and Jagannath 2014; Dutta et al., 2014; Muslim et al., 2015). In the study by Balasubramanian and Jagannath (2014), the average heart rate was measured before and after conducting the driving session. After the driving session, a marked drop in blood pressure and a significant difference in systolic and diastolic blood pressure were observed. It is possible that prolonged immobilization of the lower part of the body caused a decrease in blood pressure, resulting in poor systematic circulation. Muslim et al. (2015) showed the importance of heart rate in influencing the level of fatigue in young people and in adults. The studies by Koyano et al. (2003) and Balasubramanian and Jagannath (2014) analyzed sitting pressure. The results showed that the distribution of the pressure was not uniform. These results suggest that the impact on local physical fatigue and discomfort is likely due to the demand for static seats and the prolonged sitting posture, which impacts the thigh and buttock regions. Finally, Dutta et al. (2014) assessed the perceptual accuracy of motorcycle drivers and found greater precision and a delay in the onset of fatigue of the pupillary muscles compared to that in car drivers.

3.4.6. Questionnaires

Questionnaires, self-reports, and surveys were the most commonly implemented indirect techniques, and 74% of the studies utilized at least one survey form where the motorcyclists reported their level of discomfort, fatigue, or pain. The questionnaires were combined with direct assessments such as anthropometry, vibration assessments, and electromyography. In 11 studies, a unique methodology was developed which did not involve other direct ergonomic assessment techniques. Studies conducted with surveys showed positively the effect of postural discomfort generated by the motorcycle in 22 studies, while four studies presented neutral evidence. The questionnaires used were assessed as being of high quality in eight studies, medium quality in 14 studies, and low quality in four studies.

Survey-type studies allow for a greater number of samples to be addressed in the target population. In this case, the sample mean was 175 motorcyclists, with an average age of 28 years. While 16 studies focused on the male population, 10 evaluated participants of both sexes. The average experience of the respondents was 5 years. The average weight was 68 kg and the average height was 171 cm. Seven of the surveys were performed in the laboratory (not randomized, six; randomized, one), while the remaining 19 were performed in the field (14 not randomized; 5 randomized). The most important findings from the survey files, questionnaires, and self-reports are presented here.

In more than 16 (62%) questionnaires, information about sex, age, experience, and occupation was collected. Between 42 and 19% of the questionnaires collected information on weight, height, driving duration, type of motorcycle, manifestation of musculoskeletal disorders, exposure to vibrations, and postures adopted when riding motorcycles. Fewer than 8% of questionnaires collected information on the history of crashes, smoking habits, ethnic groups, and the capacity and type of motorcycle.

Thirty-five percent of the studies evaluated applied the body chart discomfort checklist adapted from the Borg CR-10 scale (Corlett and Bishop, 1976). The body chart discomfort checklist was used to diagram and identify the location of an individual's discomfort. Discomfort parameters have largely been evaluated by using psychological methods such as body maps, discomfort scales, or questionnaires. In 31% of the articles, a self-report form was used to collect discomfort experiment information, and 15% of the questionnaires were related to the design, comfort, and safety of the motorcycle. The Standard Nordic Questionnaires for the analysis of musculoskeletal symptoms and the self-administered questionnaire with Rehabilitation Bioengineering Group (RBG) subjective rating scale were applied by 12% of the studies. A self-administered questionnaire with RBG involves a five-point rating system in which the best score of "0" represents minimal to no pain/discomfort and a score of "5" represents severe pain. The RBG discomfort scale is similar to the RBG pain scale (Velagapudi et al., 2010). The studies which combine two comfort evaluation schemes do so by using The Body Chart Discomfort Checklist adapted from the Borg CR-10 scale and the RBG Subjective rating scale (Sai Praveen et al., 2009; Velagapudi et al., 2010), the posture analysis tool (Dutta et al., 2014), and the Standard Nordic Questionnaires (Dutta et al., 2017). Table 4 shows the strategies most used by the included studies, to gather information about postural comfort.

Table 4
Types of questionnaires for evaluating postural comfort.

Name	Number of studies	Studies
A self-administered questionnaire with the RBG Subjective rating scale	3	(Balasubramanian and Jagannath, 2014), (Velagapudi et al., 2010), (Sai Praveen and Ray, 2009)
Discomfort experiment or Questionnaire Analysis	8	(Chou and Hsiao, 2005), (Mirbod et al., 1997a,b), (Marina et al., 2013), (Amrutkar and Rajhans, 2011), (Khamis et al., 2016), (Hafzi et al., 2011), (Koyano et al., 2003), (Mirbod et al., 1997a,b)
Karolinska Sleepiness Scale (KSS)	1	(Muslim et al., 2015)
Motorcycle comfort and design ratings	4	(Stedmon et al., 2008a,b), (Robertson et al., 1996); (Dutta et al., 2014), (Dutta et al., 2017)
Posture analysis tool	2	(Dutta et al., 2014), (Dutta et al., 2017)
Questionnaire Form of Fatigue; a general questionnaire	1	(Khamis et al., 2014a,b)
Standard Nordic Questionnaires for the analysis of musculoskeletal symptoms	3	(Khamis et al., 2014a,b), (Dutta et al., 2017), (Jothi Prasanna et al., 2017)
The body chart discomfort checklist adapted from the Borg CR-10 scale	9	(Mohamad et al., 2014), (Shafiei et al., 2015), (Karuppiah et al., 2012), (Dutta et al., 2017), (Dutta et al., 2014), (Karmegam et al., 2013), (Velagapudi et al., 2010), (Sai Praveen and Ray, 2009), (Karmegam et al., 2009)
Questionnaire with Likert's scale	1	(Ramasamy et al., 2017)
The Quick Exposure Check (QEC)	1	(Rashid et al., 2015)

Some additional findings are presented below.

Among the investigations with questionnaires, the investigation by Marina et al. (2013) can be highlighted. In this study, a survey was defined, and the feelings of discomfort related to the compartment syndrome were classified into three categories. Another study by Koyano et al. (2003) employed a subjective feeling evaluation of static seating comfort. Shafiei et al. (2015) applied the body chart discomfort checklist adapted from the Borg CR-10 scale, and quantified discomforts in eight sessions, conducted with 15-minute intervals. Ramasamy et al. (2017) applied The Quick Exposure Check (QEC) as an observational tool which was developed for health practitioners to evaluate individual exposure to MSD risks. Dutta et al. (2014) and Dutta et al. (2017) applied videography and photography methods and questionnaires in their studies to assess postural stress by rapid upper limb assessment (RULA) and rapid entire body assessment (REBA).

Muslim et al. (2015) performed evaluations using the 9-scale Karolinska Sleepiness Scale (KSS). KSS is measured based on subjective feelings about sleepiness. KSS is used to define states of brain wave signals and slow eye movement. Khamis et al. (2014a,b) developed a questionnaire form based on general fatigue analysis. The questionnaire included questions about general information pertaining to motorcyclists and their perceptions of fatigue, noise and vibration, riding seat, as well as body discomfort. Rashid et al. (2015) applied a questionnaire to determine the public's perception on vehicular discomfort manifesting in various body regions. The questionnaire used the Likert's scale to rate the level of discomfort.

3.5. Effect of physical fatigue and postural discomfort on motorcyclists

After identifying the techniques applied in the assessment of physical fatigue and postural comfort, it is important to highlight the areas of the body affected by motorcycle driving as reported by each of the studies. Table 5 summarizes the affected areas of the body and those indicated as relevant in the studies evaluated. Only three studies (Moreno et al., 2011; Khamis et al., 2014a,b; Muslim et al., 2015) did not specify body areas affected by motorcycle driving, and therefore can be categorized as neutral evidence. These studies evaluated general fatigue and the relationship between driving and the environment. A total of 14 body parts affected by motorcycle driving were identified. While five studies (Stedmon et al., 2008a,b; Karmegam et al., 2009; Amrutkar and Rajhans, 2011; Dutta et al., 2014; Rashid et al., 2015) found several disorders in more than 50% of parts of the body, 13 studies showed such disorders in four to six parts of the body, and 14 reported ailments or discomfort in less than three parts of the body.

According to the areas of the body most affected by discomfort, afflictions, and fatigue in motorcyclists, the most significant area was the lower back, as reported by 63% of the studies analyzed. The shoulder and forearm areas were reported as the affected areas by 51% of the studies, while the neck area was reported by 43% of the studies. The upper back and buttocks were reported to be the most affected in 37% and 34% of studies, respectively. Conditions in the wrists, hands, and fingers were reported by 23%, those in the arms by 20%, and the hips and knees by 11% of the included articles. The lowest manifestation of discomfort, fatigue, and pain were the ankles (9%) and the thighs (6%). Fig. 3 and Table 5 show the body with details about the areas which showed the most driving-related ailments and discomfort according to the findings of the studies evaluated.

Robertson and Minter (1996) reported the difference between static and dynamic ergonomic measurements and showed that the measurement method may influence the results. In this case, the knee position of the motorcyclists was affected. Mirbod et al. (1997a,b) found that motorcyclists had numbness and stiffness in the fingers, and pain and stiffness in the shoulders. Chou and Hsiao (2005) determined that stature influences comfort, and that in taller subjects the discomfort is generated in the hips and ankles. Stedmon et al. (2008a,b) identified the elbows, forearms, upper back, and shoulders as secondary areas of discomfort. Sai Praveen and Ray (2009) identified that 95% of motorcyclists perceived discomfort in some part of the body. Karmegam et al. (2009) and

Table 5

Summary of conditions, ailments, and discomfort in the body as manifested in motorcyclists.

Author-Year	Neck	Shoulder	Arm	Forearm	Wrist	Hand/ Finger	Lower back	Upper back	Hip	Buttock	Thigh	Knee	Ankle
(Chou and Hsiao, 2005)					X		X		X				X
(Mohamad et al., 2014)	X				X		X	X		X			
(Mirbod et al., 1997a,b)		X				X							
(Khamis et al., 2014a,b)						X	X			X			
(Marina et al., 2013)				X									
(Balasubramanian and Jagannath 2014)	X	X					X	X		X			
(Stedmon et al., 2008a,b)	X	X		X	X		X	X		X			
(Shafiei et al., 2015)	X	X		X			X	X					
(Amrutkar and Rajhans, 2011)	X	X		X		X	X	X		X			
(Ramasamy et al., 2017)		X	X	X			X	X					
(Karuppiyah et al., 2012)							X	X					
(Dutta et al., 2017)	X	X				X			X		X	X	
(Marina et al., 2015)				X									
(Roseiro et al., 2016)		X	X	X									
(Dutta et al., 2014)		X	X	X	X		X		X			X	X
(Matsumoto et al., 1982)						X							
(Marina et al., 2011)				X									
(Khamis et al., 2016)	X		X	X	X		X	X		X			
(Karmegam et al., 2013)			X	X		X	X	X		X			
(Rashid et al., 2016)	X	X		X			X						
(Velagapudi et al., 2010)	X	X		X			X	X					
(Ma'arof et al., 2017)	X	X		X			X						
(Torrado et al., 2015)				X									
(Hafzi et al., 2011)	X	X					X	X	X				
(Jothi Prasanna, et al., 2017)	X				X		X						
(Koyano et al., 2003)										X	X		
(Rashid et al., 2015)	X	X	X	X	X	X	X	X		X		X	X
(Robertson et al., 1996)										X		X	
(Sai Praveen and Ray, 2009)	X	X			X		X			X			
(Karmegam et al., 2009)	X	X	X	X		X	X	X		X			
(Mirbod et al., 1997a,b)		X					X						
(Chen et al., 2009)		X	X	X			X						

Amrutkar and Rajhans (2011) found that motorcyclists did not experience any discomfort in the lower body. Karmegam et al. (2013); Velagapudi et al. (2010) and Ma'arof et al. (2017) revealed that driving discomfort correlated with the different driving positions of the motorcyclists. Hafzi et al. (2011) identified the prevalence of lower-back pain among motorcyclists. Karuppiyah et al. (2012) found a decrease in discomfort in motorcyclists, with the provision of support to the spinal column. Marina et al. (2013) identified that the braking action requires precision, and this affects the muscular activity of the forearm. Mohamad et al. (2014) showed that 64% of motorcyclists had a history of involvement in crashes when driving with fatigue. Khamis et al. (2014a,b) found that the daily vibration dose was a good indicator to evaluate the conditions of the road and its impact on the comfort of motorcyclists. Balasubramanian and Jagannath (2014) showed that driving discomfort increases with time. Roseiro et al. (2016) concluded that some adverse effects of vibrations could produce carpal tunnel syndrome, lumbosciatalgia, herniated discs, neck pain, tingling and pallor of hands, and osteoarticular injuries in the joints of the shoulder, elbows, wrists, and knees. Khamis et al. (2016) identified that motorcyclists also experienced white-finger symptoms after long hours of driving. Jothi Prasanna et al. (2017) identified musculoskeletal conditions among non-occupational motorcyclists in the last 12 months.

4. Discussion

In general, the evidence suggests that the use of motorcycles carries a risk of musculoskeletal disorders. Factors related to the design of the motorcycle such as height, angles, handlebars, seat, and footrest height, and the physical dimensions of the rider determine the posture. These ergonomic limitations should be considered when choosing motorcycles. The position is an important factor and should be evaluated as follows: How is the driver's position while driving? What are the dimensions of his body? What is the quality of the seat? How are the driver's weight and the pressure distributed during the driving? How long is the same position held? How comfortable is the driver when operating the controls? How do road conditions affect the driver? How does the motorcyclist interact with the motorcycle? What is the type of motorcycle being driven? (Amrutkar and Rajhans, 2011).

4.1. Comfort estimation

Comfort is multidimensional in nature and is affected by physical, physiological, and psychological factors (De Looze et al., 2003).

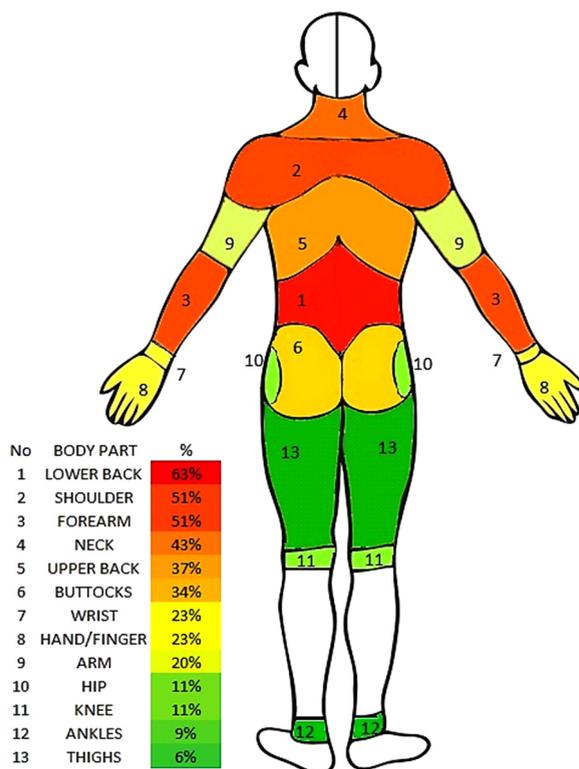


Fig. 3. Body map areas of discomfort, disease, fatigue, or pain in motorcyclists.

Descriptions of subjective experiences of fatigue have not always been reliable in the literature (Williamson et al., 2001). Fatigue or discomfort starts as a subjective sensation in the body, and it is expected that there will always be discrepancies in the quantitation of these parameters (Stedmon, 2007; Stedmon et al., 2008a,b).

Though many studies have been conducted, there is no consensus on the subjective features of motorcycling discomfort. A motorcyclist's experience of comfort can be influenced by the size ratio between the rider and the machine, the conditions of the road, postural factors, maintenance of the vehicle which influences the smoothness of the controls, previous pathologies, and style of driving, among other relevant aspects.

4.2. Muscular activity

The muscles most affected are those of the neck, shoulders, back, and lower extremities because these muscles must be maintained in a continuously contracted state without intermittent relaxation during driving (De Luca, 1984, Stock, 1991). Muscles with motor fibers that contract predominantly slowly (Type I) are more resistant to fatigue than are those with fast-twitch type motor fibers (Type II) (Basmajian & De Luca, 1985). Type I fibers cannot be called fatigue resistant under anaerobic conditions (Johnson et al., 1973). The most affected muscles in motorcycle driving are: latissimus dorsi (middle back), erector spinae (lower back), biceps (upper arm), flexor carpi ulnaris, extensor carpi radialis (forearm and wrist), and trapezius, later deltoid, and sternocleidomastoid (shoulder).

Below is a description of the activities that the various muscle groups contribute while driving. flexor carpi ulnaris and extensor carpi radialis: used in controlling the throttle, clutch, and brake levers; trapezius, posterior deltoid, sternocleidomastoid: maintain hand position while driving, controlling head motion, and absorbing any shocks to the head. The lower back muscle is used to maintain body posture. Latissimus dorsi: holds the body and absorbs any shocks that are transmitted from the road. Erector Spinae: is affected by the condition of the seat. The relevance of each of the muscles is based on their interaction with the motorcycle (Velagapudi et al., 2010; Rashid et al., 2015).

The static sitting posture creates high intramuscular pressure, which causes an obstruction to the blood flow and leads to an oxygen deficiency in the cells of the muscle tissues. Many of the movements adopted by motorcyclists seek to balance their center of gravity with the effect of decreasing pressure on the ischial spine region and that of neurovascular compression in the perineum. This is achieved by moving from an initial upright posture to a forward inclined posture to adjust the center of gravity to the thighs.

4.3. Design of motorcycles and dimensions of the motorcyclist

Many of the motorcycles available in the market are designed for specific user groups, and it is important to estimate the dimensions of the motorcyclist in static and dynamic postures. While riding a motorcycle, the driver's posture is static for a prolonged period and dynamic movement occurs when the motorcycle stops; the driver places the leg on the ground to maintain balance. The physical pressures created in such situations are related to volume, inertia, and center of mass of the motorcycle; thus, if there is no clear anthropometric fit between the rider and the vehicle, the impact on the rider is higher.

Studies conducted by [Smith et al. \(2006\)](#) identified the importance of relating the motorcyclist's postural condition to different motorcycle designs. The seated posture as while driving a motorcycle greatly affects intradiscal pressure, causing problems in the well-being of riders. Intradiscal pressures in the lumbar region of the spine are greater while sitting than while standing ([Garcia et al., 2016](#)).

The evaluated studies note that motorcycle riding establishes a postural pattern according to the adjustment of the handlebar, seat, and footrest. Several of these studies ([Karmegam et al., 2009, 2013](#)) revealed clear differences between the motorcycle adjustments necessary for men and women. Based on anthropometric evaluations, it has been reported that the forward reclining posture is the most preferred regardless of the type of motorcycle ([Karmegam et al., 2009](#)), and that motorcyclists tend to recline to improve their adjustment to the bike ([Robertson and Minter, 1996](#)).

4.4. Vibrations in motorcycles

Vibrations from the motorcycle are transmitted to the hands and arms through the grip of the handlebar, to the thighs and the tail-bone region through the seat, and to the ankles and feet through the foot support. These vibrations are caused by the vibration of the engine, the roughness of the road, and the vibration of the suspension and the chassis ([Xu et al., 2007](#)). Vibrations felt by motorcyclists have been evaluated by several studies, but the intensity reported was not adequate to cause pain. It is thought that prolonged exposure to these vibrations may cause discomfort and injury. While vibrations as low as 0.02 RMS can be perceived by humans, only those above 2 RMS can contribute to pain ([Mohamad et al., 2014](#)). The conditions on the road may radically modify the vibration measurements ([Chen et al., 2009](#); [Roseiro et al., 2016](#)). The key is not only to quantify the vibrations within a specific time interval, but to measure the level and frequency of exposure. A continuous dose accumulates in the body and leads to musculoskeletal disorders. Research conducted by [Mirbod et al. \(1997a,b, 1998\)](#) showed that the magnitude of vibration in the hands was less than that measured in the handlebar. This effect is due to the internal natural damping characteristics of the arms and hands, which absorb some of the vibrational energy.

5. Recommendations

- The use of electromyography is one of the most efficient methodologies to quantify muscle activity. For a complete measurement, recommendations of the European Recommendations for (SENIAM) projects must be followed ([Hermens et al., 1999](#); [Hermens et al., 2000](#)).
- It is important that measurement of vibrations is conducted as per recommendations by the [ISO-2631e1-I \(1997\)](#). It is thus important to perform a comprehensive range measurement with reference to the arms, and the support of the handlebar and the seat.
- Some solutions proposed in alleviating vibrations are related to improving the mechanical conditions of the motorcycle such as cushioning in handlebars and seat, stability, and resonance of the suspension and its relationship with the engine, anti-vibration gloves, rubber accessories, and absorbent materials ([Fasana and Giorcelli 2010](#); [Agostoni et al., 2012](#); [Xu et al., 2013](#); [Zou et al., 2014](#); [Tanigaki and Kaneko, 1995](#)).
- Back pain in adults has a high rate of recurrence and contributes to the manifestation of musculoskeletal disorders ([Ebe and Griffin 2000](#); [Kolich 2008](#)). Several studies propose the application of accessories to support the spinal column for improved ergonomics ([Karmegam et al., 2008](#); [Karuppiyah et al., 2011](#); [Karuppiyah et al., 2012](#)).
- Motorcycling simulation laboratories have been developed to analyze functional aspects and include the following: Motergo posture ([Fauzi et al., 2017](#)), Honda SMARTrainer Motorcycle Simulator ([Buchanan, 2008](#)), NIHON Motor-cycle Simulator ([Kishida and Kageyama, 2007](#)), UNIPD Motor-cycle Simulator ([Cossalter et al., 2009](#)), and MotorcycleSim ([Stedmon et al., 2011](#); [Stedmon, Hasseldine et al., 2011](#)). These technological advances allow for a better study of the human-machine interaction from a controlled, reliable setting, without risking the safety of individuals.
- Anthropometric studies should be oriented to potential populations when designing a motorcycle; in this way motorcycle designs can be focused on specific user populations, in contrast to being universal ([Chou and Hsiao, 2005](#); [Hsu et al., 2016](#)).
- The analysis of fatigue can be performed using different approaches: physiological, cognitive, and subjective ([Williamson et al., 2011](#); [Dawson et al., 2014](#)). These approaches showed the importance of mental processes, concentration, and mental agility in influencing the intentions, conduct, mental load and behaviors of motorcyclists ([Dutta et al., 2014](#); [Muslim et al., 2015](#); [Mizuno](#)

et al., 1996; Mizuno et al., 1998a,b; Di Stasi et al., 2009; and Ohtsuka et al., 2015).

- Therefore, it is advisable to combine and correlate the results of fatigue and comfort assessments as per direct measurements with those obtained from surveys, self-reports, or questionnaires, to obtain conclusive results. Survey techniques allow for a larger sample size since the presence of the individual is not required.
- The Borg CR-10 scale and the Standard Nordic Questionnaires for the analysis of musculoskeletal symptoms facilitates the capture of the information. Nowadays, some questionnaires focused on automobiles have been adapted (Smith et al., 2006) to be applied for motorcycles, such as the Motorcycle Seating Comfort Questionnaire (MSCQ) (Velagapudi and Ray, 2017).
- It is necessary to define a fatigue calculation method for the vehicle; such a method should integrate all the key aspects in the driving of the motorcycle, such as that developed by Barone and Lo Iacono (2015).
- A comprehensive analysis of postural comfort and physical fatigue in a motorcyclist should consider the following aspects: appropriate sample size, control groups (occupational and non-occupational drivers), ergonomic assessment considering the motorcycle's features, postures, type of motorcycle, clinical history, motorcycle dimensions, direct measurements, effort assessment, muscle activity assessment, physiological and cognitive parameters, and subjective comfort assessment.

6. Conclusion

Of the 35 investigations under review, 12 were found to be of high quality, 18 were of medium quality, and five of low quality. Most studies (83%) included evidence that physical fatigue and postural discomfort affect the performance of motorcyclists and are related to musculoskeletal conditions. In this review, 17% of the studies evaluated (6) presented neutral evidence. According to the areas of the body most affected by discomfort, musculoskeletal disorders, and fatigue in motorcyclists, the lower back was the most common, as reported by 63% of the studies analyzed, followed by the shoulders and forearms, as reported by 51% of the analyzed studies.

In conclusion, motorcycle driving has effects on postural comfort and physical fatigue. Motorcyclists are at risk of disorders of the musculoskeletal system and such disorders have become a growing public health problem throughout the world. Due to an increase in the number of motorcycles worldwide, it is important to consider the impact of these vehicles on mobility and the road safety. Future research in the field of ergonomics in motorcycles should relate physical fatigue, postural comfort, human error and the relation with the crashes.

Funding

Funding for Holman Ospina-Mateus (doctoral student) was covered by Fundación Centro de Estudios Interdisciplinarios Básicos y Aplicados (CEIBA)—Gobernación de Bolívar (Colombia).

Appendant 1. Recurrent words (n = 46) identified in 250 articles using a preliminary search

Related to the vehicle (frequency)		Related to driving and use (frequency)		Related to musculoskeletal disorders (frequency)	
Footboard	0	Anthropometry	15	Back	61
Footrest	5	Comfort	98	Cervical	9
Handlebar	30	Dynamic	0	Disorders	15
Moped	25	Discomfort	23	Epidemiology	23
Motorbike	19	Ergonomic	33	Forearm	6
Motorcycle	213	Exposure	42	Hand-Arm	13
Motorcyclist	140	Fatigue	68	Head Injury	5
Rider	250	Joint Angles	0	Herniated Disc	0
Saddle	14	Mental Workload	0	Low Back	12
Scooter	56	Physical	104	Lumbar	14
Two-Wheeled	23	Posture	61	Muscle	33
		Seat	93	Musculoskeletal	16
		Sitting	13	Pain	34
		Stability	67	Risk	138
		Static	20	Risk Factor	43
		Vibration	59	Shoulder	15
				Spine	17
				Trunk	11
				Whole-Body	0
A		B		C	

Note: Words in black color were discarded due to their low incidence in the articles. Words in red color were included in the group of key search terms because of their high incidence in the articles.

Appendant 2. Search strategy employed to search databases

Database	Search strategy
ISI WEB OF KNOWLEDGE (Topic)	Topic: (handlebar or Moped* or motorbike* or Motorcycle* or Motorcyclist* or Rider* or Scooter* or "two-wheeled*") AND Topic:(anthropometry or Comfort* or Discomfort* or Ergonomic* or fatigue or physical or posture* or seat* or stability or Static* or Vibration* or exposure*) NOT Topic: (jockey or Horse* or Equine or equitation or Equestrian or aquatic or "jet ski" or boat or chemical or veterinary) AND Topic: (back* or disorder* or Epidemiology or "hand-arm" or "Low back" or Lumbar or cervical or Muscle* or musculoskeletal* or pain* or Spine* or trunk* or shoulder* or risk* or "Risk factor*") Period: All. Indices: SCI-EXPANDED, SSCI, A&HCI, ESCL.
PUBMED (All)	(handlebar or Moped* or motorbike* or Motorcycle* or Motorcyclist* or Rider* or Scooter* or "two-wheeler*") AND (anthropometry or Comfort* or Discomfort* or Ergonomic* or fatigue or physical or posture* or seat* or stability or Static* or Vibration* or exposure*) NOT (jockey or Horse* or Equine or equitation or Equestrian or aquatic or "jet ski" or boat or chemical or veterinary) AND (back* or disorder* or Epidemiology or "hand-arm" or "Low back" or Lumbar or cervical or Muscle* or musculoskeletal* or pain* or Spine* or trunk* or shoulder* or risk* or "Risk factor*")
MEDLINE (OVID) All	((((handlebar or Moped* or motorbike* or Motorcycle* or Motorcyclist* or Rider* or Scooter* or "two wheeled*") and (anthropometry or Comfort* or Discomfort* or Ergonomic* or fatigue or physical or posture* or seat* or stability or Static* or Vibration* or exposure*)) not (jockey or Horse* or Equine or equitation or Equestrian or aquatic or "jet ski" or boat or chemical or veterinary)) and (back* or disorder* or Epidemiology or "hand-arm" or "Low back" or Lumbar or cervical or Muscle* or musculoskeletal* or pain* or Spine* or trunk* or shoulder* or risk* or "Risk factor*"))).mp. [mp=title, abstract, original title, name of substance word, subject heading word, keyword heading word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]
SCOPUS (ELSEVIER) Article title, Abstract, Keywords	((TITLE-ABS-KEY ((handlebar OR moped OR motorbike OR motorcycle OR motorcyclist OR rider OR scooter)) AND TITLE-ABS-KEY ((anthropometry OR comfort OR discomfort OR ergonomic OR fatigue OR physical OR posture OR seat OR stability OR static OR vibration OR exposure)) AND NOT TITLE-ABS-KEY ((jockey OR horse* OR equine OR equitation OR equestrian OR aquatic OR "jet ski" OR boat OR chemical OR veterinary)) AND TITLE-ABS-KEY ((back OR disorder OR epidemiology OR hand OR arm OR low OR lumbar OR cervical OR muscle OR musculoskeletal OR pain OR spine OR trunk OR shoulder OR risk OR factor OR)))
SCIENCE DIRECT (ELSEVIER)	((handlebar OR moped OR motorbike OR motorcycle OR motorcyclist OR rider OR scooter)) and ((anthropometry OR comfort OR discomfort OR ergonomic OR fatigue OR physical OR posture OR seat OR stability OR static OR vibration OR exposure)) AND LIMIT-TO (cids, "271664,271074,271136,271707,271795,271441","Accident Analysis & Prevention, The Lancet, Injury, Journal of Safety Research, Transportation Research Part A: Policy and Prac..., Applied Ergonomics").
EBSCO TI-ABS	"TI (Moped or motorbike or Motorcycle or Motorcyclist or "two-wheeler" or Rider or Scooter or handlebar or saddle or footrest or footboard) AND AB – TI (anthropometry or Comfort or dynamic or Discomfort or Ergonomic or fatigue or "Mental workload" or physical or posture or seat or Sitting or stability or Static or Vibration or "joint angle") NOT TI (jockey or Horse or Equine or equitation or Equestrian or aquatic or "jet ski" or boat)
EMBASE TAK	(moped OR motorbike OR motorcycle OR motorcyclist OR 'two-wheeler' OR rider OR scooter OR handlebar OR saddle OR footrest OR footboard) AND (anthropometry OR comfort OR dynamic OR discomfort OR ergonomic OR fatigue OR 'mental workload' OR physical OR posture OR seat OR sitting OR stability OR static OR vibration OR 'joint angle') NOT (jockey OR horse OR equine OR equitation OR equestrian OR aquatic OR 'jet ski' OR boat)
CINAHL	(Moped or motorbike or Motorcycle or Motorcyclist or "two wheeler" or Rider or Scooter or handlebar or saddle or footrest or footboard) AND (anthropometry or Comfort or dynamic or Discomfort or Ergonomic or fatigue or "Mental workload" or physical or posture or seat or Sitting or stability or Static or Vibration or "joint angle") NOT ((jockey or Horse or Equine or equitation or Equestrian or aquatic or "jet ski" or boat) AND (Back or disorder* or Epidemiology or "hand-arm vibration" or "Head injury" or "herniated disc" or "Low back" or Lumbar or cervical or Muscle* or musculoskeletal* or pain* or Spine or trunk or "whole-body vibration" or shoulder* or forearm* or risk* or "Risk factor*"))
Others	(SAGE JOURNALS ONLINE, SCIELO, IEEE XPLOR, WILEY ONLINE LIBRARY, PROQUEST, GOOGLE SCHOLAR ((Moped or motorbike or Motorcycle or Motorcyclist or "two-wheeler" or Rider or Scooter or handlebar or saddle or footrest or footboard)) AND NOT (jockey or Horse or Equine or equitation or Equestrian or aquatic or "jet ski" or boat).

Appendant 3. Level 1. Priority filter

The bibliographic search was supported by the reference software (ENDNOTE 8 × ®). The most significant words were defined in two subsets that allowed a refined selection by title, summary, and keywords, as follows:

- I. Motorbike, Motorcycle, Motorcyclist
- II. Comfort, Discomfort, Ergonomic, Fatigue, Physical, Posture, Vibration, Disorders, Hand-arm, Low Back, Muscle, Musculoskeletal, Risk.

Appendant 4. Level 2. Relevance filter

The title of the article and the full summary of the prioritized articles were reviewed, and the manuscripts were classified by their scope. The results identified four study segments related to the following:

- I. Motorcycling or motorcyclists, but without relevance to the research question.
- II. Mechanical and physical analysis of motorcycles that exclude the experience of driving motorcycles.
- III. Accidents, risk factors, incidents, injuries related to unforeseen events, and imprudence or road infractions.
- IV. Motorcyclist and motorcycle interaction and ergonomics, or health issues related to fatigue, comfort, and posture conditions.

Appendant 5. Evaluation of 144 articles by relevance

The values varied from "important" (1), "something important" (2), to "very important" (3). The highest possible weighted score was 10 points. The weightage was assigned by the authors, in which each question was assessed for impact. Thus, all the above-mentioned questions were not given equal weightage. Thus, the first question was considered the most important and the third as the least important.

*P: Partial; M: Moderate; S: Strong; Q: question.

Author	Questions (Weighing)					Weighted Value	Category	Author	Questions (Weighing)					Weighted Value	Category
	1Q (3)	2Q (2)	3Q (1)	4Q (2)	5Q (2)				1Q (3)	2Q (2)	3Q (1)	4Q (2)	5Q (2)		
(Sukor et al., 2017)	0	2	0	0	1	30%	P	(Robertson and Porter, 1988)	3	0	0	2	0	50%	M
(Frendo et al., 2002)	3	0	1	0	0	40%	M	(Robertson et al., 2009)	0	0	0	2	2	40%	M
(Bach et al., 2015)	0	2	0	1	0	30%	P	(Winkes et al., 2016)	0	2	0	0	0	20%	P
(Chou and Hsiao, 2005)	3	2	1	2	0	80%	S	(Lindsay et al., 2013)	0	0	0	2	0	20%	P
(Jagannath and Balasubramanian, 2014)	0	2	0	1	0	30%	P	(Sakashita et al., 2014)	0	2	0	0	1	30%	P
(Mohamad et al., 2014)	3	2	0	2	0	70%	S	(Gillen, 1998)	3	2	0	0	0	50%	M
(Mirbod et al., 1997)	3	2	0	2	0	70%	S	(Horberry et al., 2008)	3	2	0	0	0	50%	M
(Robertson 1986)	3	2	0	1	0	60%	M	(Ma'arof et al., 2014)	3	0	0	1	0	40%	M
(Gil-Moreno-De-Mora et al., 2017)	3	1	0	2	0	60%	M	(Stedmon et al., 2011)	0	2	1	1	0	40%	M
(Khamis et al., 2014a,b)	3	2	0	2	0	70%	S	(Stedmon, 2007)	3	2	0	1	0	60%	M
(Konttinen et al., 2007)	0	2	0	1	0	30%	P	(Ma'arof, et al., 2014)	3	0	0	0	0	30%	P
(Konttinen et al., 2008)	0	2	0	1	0	30%	P	(Rashid et al., 2014)	0	0	1	2	1	40%	M
(Ioannis et al., 2010)	0	2	0	0	0	20%	P	(Karmegam et al., 2013)	3	2	0	2	0	70%	S
(Akinbo et al., 2008)	3	2	0	0	0	50%	M	(Said et al., 2015)	3	2	0	0	0	50%	M
(Liguori et al., 2013)	3	0	0	0	0	30%	P	(Rashid et al., 2016)	3	2	0	2	0	70%	S
(Paiman et al., 2014)	0	2	0	0	0	20%	P	(Erdelyi et al., 2012)	2	0	1	0	0	30%	P
(Jeschke et al., 2006)	3	0	0	2	0	50%	M	(Velagapudi et al., 2010)	2	1	1	2	1	70%	M
(Goubier and Saillant, 2003)	3	0	0	0	0	30%	P	(Ma'arof et al., 2017)	3	2	0	2	0	70%	S
(Hale et al., 2007)	2	0	1	0	0	30%	P	(Gyi and Porter, 1998)	0	2	0	2	0	40%	M
(Marina et al., 2013)	3	2	0	2	0	70%	S	(Simões et al., 2016)	3	2	0	0	0	50%	M
(Mizuno et al., 1998a,b)	3	2	0	0	1	60%	M	(Torrado et al., 2015)	3	2	0	2	0	70%	S
(Barone and Curcio, 2004)	2	0	1	0	0	30%	P	(Cheli et al., 2011)	0	0	1	0	0	10%	P
(Karmegam et al., 2008)	0	0	1	2	0	30%	P	(Vogel and Vogt, 2016)	3	2	0	0	1	60%	M
(Karuppiyah et al., 2011)	0	0	1	2	0	30%	P	(Lai and Aritejo, 2013)	0	2	0	0	0	20%	P
(Schmitz et al., 2015)	2	0	1	0	0	30%	P	(Sánchez-Muñoz et al., 2011)	0	2	0	0	0	20%	P
(Patil et al., 2014)	0	0	1	0	0	10%	P	(Ascensão et al., 2008)	0	2	0	2	0	40%	M
(Lai et al., 2003)	0	0	1	0	0	10%	P	(Ma et al., 2003)	3	2	0	0	0	50%	M

(Balasubramanian and Jagannath, 2014)	3	2	0	2	0	70%	S	(Moreno et al., 2011)	3	2	0	2	0	70%	S
(Sabbah and Bubb, 2008)	3	2	0	0	0	50%	M	(Khamis et al., 2014a,b)	3	2	0	2	0	70%	S
(Velagapudi and Ray 2017)	3	2	1	0	0	60%	S	(Hafzi et al., 2011)	3	2	0	2	0	70%	S
(Lal et al., 2003)	1	2	0	0	0	30%	P	(Manes, 2012)	3	2	0	1	0	60%	M
(Stedmon et al., 2008a,b)	3	2	0	2	0	70%	S	(Jothi et al., 2017)	3	2	0	2	0	70%	S
(Lin et al., 2006)	3	0	1	0	0	40%	M	(Stedmon et al., 2008a,b)	0	2	0	0	0	20%	P
(Mateo-March et al., 2013)	0	2	0	0	1	30%	P	(Ma'arof and Ahmad, 2012)	0	0	1	2	1	40%	M
(Zagol and Krasuski, 2010)	0	2	0	0	1	30%	P	(Reeder et al., 1997)	0	2	0	0	1	30%	P
(Shafiei et al., 2015)	3	2	1	1	0	70%	S	(Israr et al., 2007)	2	1	1	0	1	50%	S
(Matsumoto et al., 1986)	3	2	0	1	0	60%	M	(Koyano et al., 2003)	3	2	1	1	0	70%	S
(Shivakumara and Sridhar, 2010)	3	0	1	0	0	40%	M	(Jevtić et al., 2015)	0	0	1	0	2	30%	P
(Amrutkar and Rajhans, 2011)	3	2	0	2	0	70%	S	(Zhongming et al., 2007)	3	2	0	0	0	50%	M
(Aupetit and Espie 2012)	3	0	0	0	0	30%	P	(Li et al., 2009)	0	2	1	0	1	40%	M
(Ohtsuka et al., 2015)	0	2	0	0	1	30%	P	(Brearley et al., 2014)	0	2	0	0	1	30%	P
(Mizuno et al., 1998a,b)	2	1	0	0	0	30%	P	(Chavan et al., 2011)	0	0	1	0	0	10%	P
(Ramasamy et al., 2017)	3	2	0	2	0	70%	S	(Di Stasi, et al., 2009)	0	2	0	0	1	30%	P
(Conrad and Marklin, 2014)	3	2	0	1	0	60%	M	(Alias et al., 2016)	3	0	0	2	1	60%	M
(Karuppiyah et al., 2012)	3	2	0	2	0	70%	S	(Barone and Lo Iacono, 2015)	3	0	1	0	0	40%	M
(Dutta et al., 2017).	2	2	0	1	1	60%	M	(Stedmon, 2007)	3	2	0	1	0	60%	M
(Suresh et al., 2013)	0	0	1	0	0	10%	P	(Filaire et al., 2007)	3	2	0	0	0	50%	M
(Talib et al., 2015)	3	2	0	0	0	50%	M	(Rashid et al., 2015)	3	2	0	2	0	70%	S
(Cho et al., 2014)	0	0	0	2	0	20%	P	(Centemeri et al., 2005)	1	1	0	2	0	40%	M
(Arthur, 2005)	0	0	0	0	2	20%	P	(Yokomori et al., 1989)	3	2	0	1	0	60%	M
(Haworth and Rowden, 2006)	3	0	0	0	2	50%	M	(Hsu, Liu et al., 2016)	0	2	1	0	1	40%	M
(Muslim et al., 2015)	3	2	0	0	2	70%	S	(Karmegam et al., 2009)	3	2	0	1	0	60%	S
(Marina et al., 2015)	3	2	1	2	0	80%	S	(Robertson and Minter, 1996)	3	2	0	2	0	70%	M
(Roseiro et al., 2016)	3	2	0	2	0	70%	S	(Mizuno and Sugizaki, 1995)	3	2	0	0	0	50%	M
(D'Artibale et al., 2008)	0	2	0	2	0	40%	M	(Shivakumara and Sridhar, 2010)	3	2	0	0	0	50%	S
(D'Artibale et al., 2007)	0	2	0	2	0	40%	M	(Sai Praveen and Ray, 2009)	3	2	0	2	0	70%	S
(Arimoto et al., 2002)	0	2	0	2	0	40%	M	(Karmegam et al., 2009)	3	2	0	2	0	70%	S
(Morosi et al., 2015)	0	2	0	2	0	40%	M	(Mirbod, Inaba et al., 1997)	3	2	0	2	0	70%	P
(Nimura et al., 1990)	3	2	0	1	0	60%	M	(Rehn et al., 2005)	0	2	0	1	0	30%	P
(Dutta et al., 2014)	3	2	0	2	0	70%	S	(da Trindade et al., 2015)	0	0	0	2	0	20%	M
(Jeyakumar and Gandhinathan, 2014)	0	2	1	0	0	30%	P	(Smith et al., 2006)	3	0	1	1	0	50%	M
(Haworth and Rowden, 2006)	3	0	0	0	2	50%	M	(Martín et al., 2015)	0	2	0	1	0	30%	M

(Koizumi et al., 2004)	2	0	1	0	0	30%	P	(Noh et al., 2017)	3	2	0	0	0	50%	P
(Owen et al., 2015)	0	0	0	2	1	30%	P	(Khamis et al., 2014a,b)	3	2	0	1	0	60%	M
(Matsumoto, 1981)	3	2	0	1	0	60%	M	(Tunncliff et al., 2012)	0	2	0	0	1	30%	M
(Matsumoto et al., 1982)	3	2	0	2	0	70%	S	(Rashid et al., 2015)	3	0	1	0	0	40%	P
(Cossalter et al., 2006)	2	1	0	0	0	30%	P	(Sakashita et al., 2014)	0	2	0	0	2	40%	S
(Mizuno et al., 1996)	3	2	0	0	0	50%	M	(Tominaga, 1994)	3	2	0	1	0	60%	M
(Marina et al., 2011)	3	2	0	2	0	70%	S	(Diyana et al., 2017)	0	0	0	2	2	40%	M
(Hassan et al., 2002)	0	2	0	1	0	30%	P	(Bentley et al., 1982)	0	0	0	2	1	30%	P
(Tianyi et al., 2017)	2	0	0	1	0	30%	P	(Dalawai and Vyas, 2015)	3	0	1	0	0	40%	M
(Khamis et al., 2016)	3	2	0	2	0	70%	S	(Stark et al., 1990)	3	0	0	2	1	60%	M
								(Chen et al., 2009)	3	2	0	2	0	70%	S

Appendant 6. Compared to the quality rating of the journal (Quartile-SJR) Vs Quality filter

Author	Quality Qualification	Journal Quality-SJR-2017
(Marina et al., 2013)	89%	75%
(Balasubramanian and Jagannath, 2014)	89%	100%
(Mirbod et al., 1997)	82%	100%
(Marina et al., 2015)	82%	100%
(Marina et al., 2011)	82%	75%
(Hafzi et al., 2011)	75%	25%
(Chen et al., 2009)	75%	75%
(Torrado et al., 2015)	73%	100%
(Karuppiyah et al., 2012)	71%	100%
(Karmegam et al., 2013)	71%	75%
(Velagapudi et al., 2010)	71%	75%
(Karmegam et al., 2009)	71%	25%
(Chou and Hsiao, 2005)	68%	75%
(Mirbod et al., 1997)	68%	100%
(Dutta et al., 2014)	64%	25%
(Khamis et al., 2016)	64%	25%
(Rashid et al., 2015)	63%	50%
(Mohamad et al., 2014)	61%	50%
(Rashid et al., 2016)	61%	25%
(Moreno et al., 2011)	61%	50%
(Robertson and Minter, 1996)	61%	100%
(Ramasamy et al., 2017)	59%	25%
(Dutta et al., 2017)	57%	25%
(Muslim et al., 2015)	57%	75%
(Matsumoto et al., 1982)	57%	75%
(Stedmon et al., 2008a,b)	55%	25%
(Shafei et al., 2015)	55%	50%
(Amrutkar and Rajhans, 2011)	55%	25%
(Ma'arof et al., 2017)	54%	25%
(Koyano et al., 2003)	50%	100%
(Roseiro et al., 2016)	48%	100%
(Khamis et al., 2014a,b)	48%	25%
(Sai Praveen and Ray, 2009)	45%	25%
(Khamis et al., 2014a,b)	39%	25%
(Jothi Prasanna et al., 2017)	32%	25%

Sample mean = 0.0465714, sample median = 0.07, sample standard deviation = 0.274868

t-test

Null hypothesis: mean = 0; Alternative: not equal

Computed t statistic = 1.00237, P-Value = 0.323245

Do not reject the null hypothesis for alpha = 0.05.

Sign test

Null hypothesis: median = 0; Alternative: not equal

Number of values below hypothesized median: 14, number of values above hypothesized median: 20

Large sample test statistic = 0.857493 (continuity correction applied), P-Value = 0.391171

Do not reject the null hypothesis for alpha = 0.05.

Signed rank test

Null hypothesis: median = 0; Alternative: not equal

Average rank of values below hypothesized median: 16.6429, average rank of values above hypothesized median: 18.1

Large sample test statistic = 1.09468 (continuity correction applied), P-Value = 0.273657

Do not reject the null hypothesis for alpha = 0.05.

Chi-square test

Null hypothesis: sigma = 1.0; Alternative: not equal; Computed chi-square statistic = 2.56879, P-Value = 0

Reject the null hypothesis for alpha = 0.05.

The StatAdvisor

This pane displays the results of tests concerning the population from which the sample of Paper Quality-Journal Quality is derived. The t-test tests the null hypothesis that the mean Paper Quality-Journal Quality equals 0.0 versus the alternative hypothesis that the mean Paper Quality-Journal Quality is not equal to 0.0. Since the P-value for this test is greater than or equal to 0.05, we cannot reject the null hypothesis at the 95.0% confidence level. The sign test tests the null hypothesis that the median Paper Quality-Journal Quality equals 0.0 versus the alternative hypothesis that the median Paper Quality-Journal Quality is not equal to 0.0. It is derived by counting the number of values above and below the hypothesized median. Since the P-value for this test is greater than or equal to 0.05, we cannot reject the null hypothesis at the 95.0% confidence level. The signed rank test evaluates the null hypothesis that the median Paper Quality-Journal Quality equals 0.0 versus the alternative hypothesis that the median Paper Quality-Journal Quality is not equal to 0.0. It is based on comparing the average ranks of values above and below the hypothesized median. Since the P-value for this test is greater than or equal to 0.05, we cannot reject the null hypothesis at the 95.0% confidence level. The sign and signed rank tests are less sensitive to the presence of outliers but are less powerful than the t-test if the data come from a single normal distribution.

The chi-square test tests the null hypothesis that the standard deviation of the Paper Quality-Journal Quality equals 1.0 versus the alternative hypothesis that the standard deviation of Paper Quality-Journal Quality is not equal to 1.0. Since the P-value for this test is less than 0.05, we can reject the null hypothesis at the 95.0% confidence level.

Appendant 7. Summary of the characteristics of the study population

The average sample size was 135 (range: 2 to 957 people). Two studies had a sample size of 957 people (Karmegam et al., 2009; Karmegam et al., 2013). Ranges or age averages were reported by 32 studies. In these publications, the average age of motorcyclists was 28 years. Both men and women were included in 10 articles, while only men were evaluated in 25 articles. The level of experience of the drivers (in years) was reported by 27 articles; this experience was more than 5 years, with a broad range (range, 1 to 14 years). The profile of the evaluated drivers included students, policemen, athletes, dispatchers, domiciliary workers, and postmen. In 16 articles, the weight and stature of the motorcyclists was estimated. The average weight was 67 kg (range, 57 to 79 kg), and the average height was 171 cm (range, 163 to 176 cm). In general terms, 74% of the selected studies considered a quality factor in their sample size. The size of the sample varied based on the type of ergonomic measurement. Studies using indirect measurement techniques included larger sample sizes, in contrast those in studies using direct measurement techniques. A summary of the characteristic of the studies see Fig. A7.1.

The different data evaluation techniques used in the included articles are highlighted in Fig. A7.2.

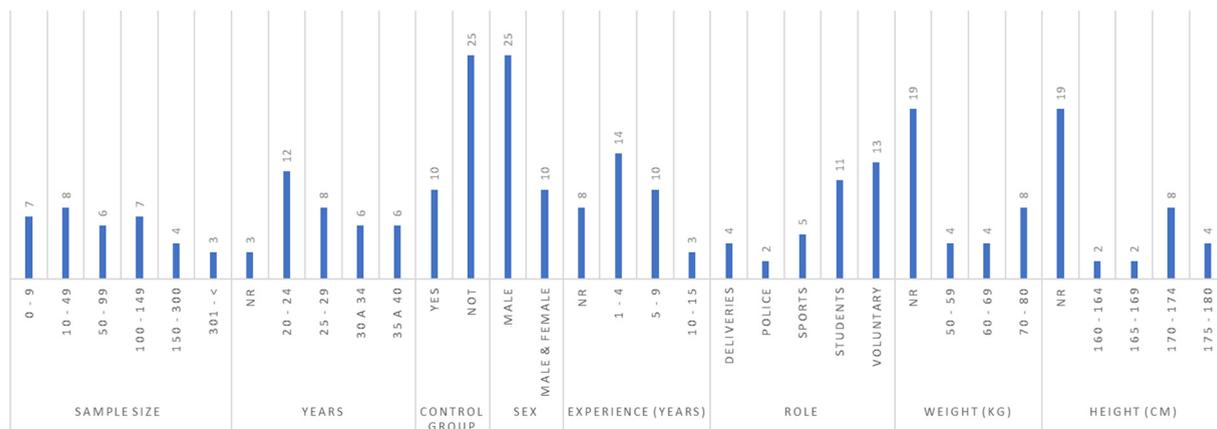


Fig. A7.1. Summary of the characteristics of the study population.

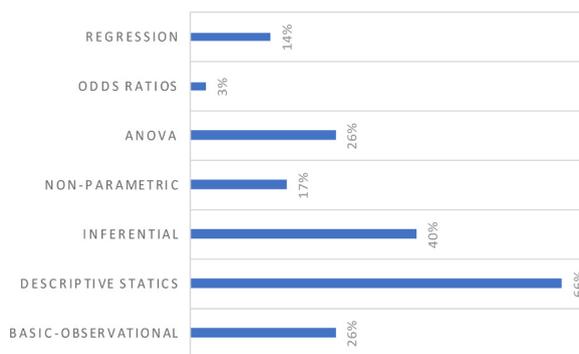


Fig. A7.2. Distribution of articles according to data analysis techniques.

Appendant 8. Summary of the direct and indirect measurement techniques

Of the 35 studies evaluated, 14 studies used direct and indirect measurement techniques. While nine studies applied direct measurement techniques, 12 used indirect measurement techniques. The studies conducted by Dutta et al. (2014) involved five direct and indirect techniques, while those by Marina et al. (2013) and Muslim et al. (2015) involved three techniques. Ten investigations involved the use of at least one direct and one indirect technique. Table A8.1 summarizes the techniques implemented by the studies included in this review.

Within the direct measurement methods, the most implemented technique (23%) was electromyography and vibration analysis. Questionnaires, surveys, or self-reports were applied in 74% (26) of the included studies. Table A8.2 summarizes the methods applied in the articles evaluated. The combination of anthropometry with questionnaires and that of electromyography with questionnaires was applied in five studies. Vibration analysis and questionnaires were used in four articles. Finally, heart rate monitoring combined with questionnaires was used in three articles.

Table A8.1

Summary of the direct and indirect measurement techniques applied in the reviewed studies.

Direct Measurement	Indirect measurement		
	Questionnaire	Videography and photography	NA*
Anthropometry	(Chou and Hsiao, 2005) [M: +]; (Stedmon et al., 2008a, 2008b) [M: +]; (Amrutkar and Rajhans 2011) [M: +]; (Robertson and Minter, 1996) [M: N]; (Dutta et al., 2014) [M: +]	(Dutta et al., 2014) [M: +]	
Vibration measurement	(Mohamad et al., 2014) [M: +]; (Mirbod et al.,1997) [H: +]; (Khamis et al., 2014a, 2014b) [L: +]; (Dutta et al., 2014) [M: +]	(Dutta et al., 2014) [M: +]	(Roseiro et al., 2016) [L: +]; (Matsumoto et al., 1982) [M: +]; (Moreno et al., 2011) [M: N]; (Chen et al., 2009) [H: N]
Dynamometric	(Marina et al., 2013) [H: +]		(Marina et al., 2015) [H: +]; (Marina et al., 2011) [H: +]; (Torrado et al., 2015) [H: +]
Electromyography	(Marina et al., 2013) [H: +]; (Balasubramanian et al., 2014) [H: +]; (Velagapudi et al., 2010) [H: +]; (Rashid et al., 2015) [M: +]		(Marina et al., 2011) [H: +]; (Rashid et al., 2016) [M: +]; (Ma'arof et al., 2017) [M: +]; (Torrado et al., 2015) [H: +]
Seat pressure analysis.	(Balasubramanian et al., 2014) [H: +]		
Heart rate	(Balasubramanian et al., 2014) [H: +]; (Muslim et al., 2015) [M: N]; (Dutta et al., 2014) [M: +]	(Dutta et al., 2014) [M: +]	
Blood pressure analysis	(Balasubramanian et al., 2014) [H: +]; (Muslim et al., 2015) [M: N]		
Others*	(Dutta et al., 2014) [M: +]	(Dutta et al., 2014) [M: +]	(Matsumoto et al., 1982) [M: +]
NA*	(Shafiei et al., 2015) [M: +]; (Ramasamy et al., 2017) [M: +]; (Khamis et al., 2014a, 2014b) [L: N]; (Hafzi et al., 2011) [H: +]; (Jothi Prasanna et al., 2017) [L: +]; (Karuppiyah et al., 2012) [H: +]; (Sai Praveen, 2009) [L: +]; (Karmegam et al., 2009) [H: +]; (Mirbod et al., 1997) [M: +]; (Dutta et al., 2017) [M: +]; (Khamis et al., 2016) [M: +]; (Karmegam et al., 2013) [H: +]	(Dutta et al., 2017) [M: +]	

Format: Study [Quality: Direction of Evidence].

* Others: Goniometry. Fusion threshold, skin temperature and the nail press test. NA: Not Applicable.

Table A8.2
Summary of direct and indirect measurement techniques applied in studies.

Direct measurement	Number of Studies	% of Studies
Anthropometry	5	14%
Blood pressure analysis	2	6%
Dynamometric	4	11%
Electromyography	8	23%
Heart rate	3	9%
Others	4	11%
Seat pressure analysis.	2	6%
Vibration measurement	8	23%
NA	12	34%
Indirect Measurement	Number of Studies	% of Studies
Questionnaire	26	74%
Videography and photography	2	6%
NA	9	26%

Of the 12 articles evaluated and categorized as high-quality articles, 42% (5) used muscle analysis with superficial electromyography. While 67% (8) of the studies applied questionnaires, 30% (4) performed effort measurements in the hand using a dynamometer. Two publications included vibration measurement. Of the 18 articles categorized as medium quality articles, 77% (14) used surveys, 28% (5) applied anthropometric measurements, and 17% (3) applied electromyography measurements. Of the five articles categorized as low-quality articles, the majority implemented questionnaires and self-reports. In the articles categorized as presenting neutral evidence (6), the most implemented technique was the self-report questionnaire. None of these articles applied an analysis of muscle activity and effort. Next, an analysis of the most relevant techniques implemented in the study of physical fatigue and unacceptability experienced by motorcyclists was conducted; this analysis was aimed at determining the key factors and relevant aspects related to postural and muscular discomforts as reported by motorcyclists, to understand how these aspects were evaluated in the different studies.

References

- Agostoni, S., Cheli, F., Leo, E., Pezzola, M., 2012. Methodology to design a vibration absorption footplate for motorcycle application: from phenomena investigation to prototype performance evaluation. *Mech. Syst. Signal Process.* **30**, 296–305.
- Alias, A.N., Karupiah, K., Tamrin, S.B.M., Abidin, E.Z., Shafie, U.K.M., Sambasivam, S., 2016. Risk factors of muscular discomfort among motorcyclist- review article. *Iran. J. Public Health* **45** (1), 35–43.
- Amrutkar, A.S., Rajhans, N., 2011. Ergonomic posture for motorcycle riding (International Conference on Innovative Science and Engineering Technology RAJKOT). V. V. P. E. College, India.
- Balasubramanian, V., Jagannath, M., 2014. Detecting motorcycle rider local physical fatigue and discomfort using surface electromyography and seat interface pressure. *Transp. Res. Part F* **22**, 150–158.
- Barone, S., Lo Iacono, G., 2015. Robust dynamic comfort modeling for motorcycle riding. *Hum. Factors Ergon. Manuf. Serv. Ind.* **25** (2), 239–250.
- Brewer, S., Van Eerd, D., Amick III, B.C., Irvin, E., Daum, K.M., Gerr, F., Moore, J.S., Cullen, K., Rempel, D., 2006. Workplace interventions to prevent musculoskeletal and visual symptoms and disorders among computer users: a systematic review. *J. Occup. Rehabil.* **16** (3), 317.
- Bridger, R., 2008. Introduction to Ergonomics. Crc Press.
- Buchanan, J., 2008. Honda SMARTrainer.
- Chen, H.C., Chen, W.C., Liu, Y.P., Chen, C.Y., Pan, Y.T., 2009. Whole-body vibration exposure experienced by motorcycle riders - An evaluation according to ISO 2631-1 and ISO 2631-5 standards. *Int. J. Ind. Ergon.* **39** (5), 708–718.
- Cheng, A.S., Ng, T.C., Lee, H.C., 2011. A comparison of the hazard perception ability of accident-involved and accident-free motorcycle riders. *Accid. Anal. Prev.* **43** (4), 1464–1471.
- Chou, J.-R., Hsiao, S.-W., 2005. An anthropometric measurement for developing an electric scooter. *Int. J. Ind. Ergon.* **35** (11), 1047–1063.
- Corlett, E.N., Bishop, R., 1976. A technique for assessing postural discomfort. *Ergonomics* **19** (2), 175–182.
- Cossalter, V., Lot, R., Massaro, M. and Sartori, R., 2009. Development and testing of assistant rider systems with the UNIPD motorcycle riding simulator. In: *Proceedings of the XIX Congresso Aimet Associazione Italiana di Meccanica Teorica e Applicata*, Italy.
- Dawson, D., Searle, A.K., Paterson, J.L., 2014. Look before you (s) leep: evaluating the use of fatigue detection technologies within a fatigue risk management system for the road transport industry. *Sleep. Med. Rev.* **18** (2), 141–152.
- De Looze, M.P., Kuijt-Evers, L.F., Van Dieen, J., 2003. Sitting comfort and discomfort and the relationships with objective measures. *Ergonomics* **46** (10), 985–997.
- Di Stasi, L.L., Alvarez-Valbuena, V., Canas, J.J., Maldonado, A., Catena, A., Antoli, A., Candido, A., 2009. Risk behaviour and mental workload: multimodal assessment techniques applied to motorbike riding simulation. *Transp. Res. Part F-Traffic Psychol. Behav.* **12** (5), 361–370.
- Dutta, K., Basu, B., Sen, D., 2014. Identification and quantification of stressors affecting motorized two wheeler riders: an ergonomic attempt. *Int. J. Res.* **2**, 13–25.
- Dutta, K., Basu, B., Sen, D., 2017. Evaluation of postural, psychosocial stress and driver behaviour of motorbike riders in India. *Occup. Ergon.* **13** (S1), 25–36.
- Ebe, K., Griffin, M.J., 2000. Qualitative models of seat discomfort including static and dynamic factors. *Ergonomics* **43** (6), 771–790.
- Fasana, A., Giorcelli, E., 2010. A vibration absorber for motorcycle handles. *Meccanica* **45** (1), 79–88.
- Fauzi, W.M.S.B.W., Omar, A.R.B. and Rashid, H.B., 2017. "Enhancement of Postura MotergoTM: From an Ergonomic Motorcycle Test Rig to a Full-Scale Simulator".
- Garcia, M.F.M., Jiménez, L.Q., Solano, L.B., 2016. Relación entre el dolor lumbar y los movimientos realizados en postura sedente prolongada. *Revisión de la literatura. Salud Uninorte* **32** (1).
- Gillen, L., 1998. Motorcycle rider fatigue survey results, Retrieved 14/3/06 from www.gillengineering.com/fatigue%20paper.htm.
- Hafzi, M.M., Rohayu, S., Faradila, P.N., Wong, S., 2011. Prevalence and risk factors of musculoskeletal disorders of motorcyclists. *Malays. J. Ergon.* **1**.
- Haworth, N.L., Rowden, P.J., 2006. Investigation of Fatigue Related Motorcycle Crashes-literature Review (RSD0261) (Report to VicRoads). Queensland University of Technology.

- Hedberg, G., 1987. Epidemiological and ergonomic studies of professional drivers. Solna.
- Hermens, H.J., Freriks, B., Disselhorst-Klug, C., Rau, G., 2000. Development of recommendations for SEMG sensors and sensor placement procedures. *J. Electromyogr. Kinesiol.* **10** (5), 361–374.
- Hermens, H.J., Freriks, B., Merletti, R., Stegeman, D., Blok, J., Rau, G., Disselhorst-Klug, C., Hägg, G., 1999. European recommendations for surface electromyography. *Roessingh Res. Dev.* **8** (2), 13–54.
- Higgins, J.P., Green, S., 2011. *Cochrane Handbook for Systematic Reviews of Interventions*. John Wiley & Sons.
- Horberry, T., Hutchins, R. and Tong, R., 2008. "Motorcycle rider fatigue-a review." Road Safety Research Report.
- Horswill, M.S., Helman, S., 2003. A behavioral comparison between motorcyclists and a matched group of non-motorcycling car drivers: factors influencing accident risk. *Accid. Anal. Prev.* **35** (4), 589–597.
- Hsu, C.H., Liu, B.S., Jhuang, S.L., Li, Y.C., 2016. The Study of Ergonomic Evaluation and Critical Design Factors for Electric Scooter (2016 International Conference on Applied System Innovation, IEEE ICASI 2016). Institute of Electrical and Electronics Engineers Inc.
- ISO-2631e1-I, 1997. Mechanical vibration and shock Evaluation of human exposure to wholebody vibration - Part 1 General requirements.
- ISO-5349e1-I, 2001. Mechanical vibrations. Measurement and evaluation of human exposure to hand-transmitted vibration. Part 1: General requirements.
- Jothi Prasanna, K., Narendrakumar, J., Manivannan, M., Sivakumar, V.P.R., 2017. Prevalence of musculoskeletal disorders among non-occupational motorcyclists. *Int. J. Pharma. Biol. Sci.* **8** (4), B552–B556.
- Karmegam, K., Ismail, M., Mohd Sapuan, S., Ismail, N., Shamsul Bahri, M.T. and Seetha, P., 2009. "Study of prevalence of self reported discomfort among motorcyclist." Karmegam, K., Ismail, M., Sapuan, S., Ismail, N., Shamsul Bahri, M., Shuib, S., Seetha, P., 2009. A study on motorcyclist's riding discomfort in Malaysia. *Eng. e-Trans.* **4** (1), 39–46.
- Karmegam, K., Ismail, M.Y., Sapuan, S.M., Ismail, N., 2008. Conceptual design and prototype of an ergonomic back-leaning posture support for motorbike riders. *J. Sci. Ind. Res.* **67** (8), 599–604.
- Karmegam, K., Sapuan, S.M., Ismail, M.Y., Ismail, N., Bahri, M.T.S., Seetha, P., 2013. Motorcyclist's riding discomfort in Malaysia: comparison of BMI, riding experience, riding duration and riding posture. *Hum. Factors Ergon. Manuf. Serv. Ind.* **23** (4), 267–278.
- Karuppiyah, K., Salit, M.S., Ismail, M.Y., Ismail, N., Tamrin, S., 2012. Evaluation of motorcyclist's discomfort during prolonged riding process with and without lumbar support. *An. da Acad. Bras. De Ciências* **84** (4), 1169–1188.
- Karuppiyah, K., Salit, M.S., Ismail, M.Y., Ismail, N., Tamrin, S.B.M., 2011. Conceptual design of motorcycle's lumbar support using motorcyclists' anthropometric characteristics. *Maejo Int. J. Sci. Technol.* **5** (1), 69–82.
- Khamis, N., Nuawi, M., Deros, B., Ismail, F., Mohamad, D., Md Tahir, N., 2014a. Assessment of whole body vibration exposure among motorcyclist in Malaysia under different speeds and different road profiles: a preliminary study. *Adv. Environ. Biol.* **8** (15), 160–163.
- Khamis, N.K., Deros, B., Mismail, F.R., Tahir, N.H.M., 2016. Motorcycle deliveryman's perceptions on riding conditions. *Malays. J. Public Health Med.* **1** (Specialissue1), 1–5.
- Khamis, N.K., Deros, B.M. and Nuawi, M.Z. (2014b). A preliminary study on motorcyclists' perceptions of fatigue risk factors. In: *Proceedings of the 4th International Conference on Noise, Vibration and Comfort*, NVC 2012. Kuala Lumpur. 471: 178-183.
- Kishida, T. and Kageyama, I., 2007. A study on riding simulator for motorcycle. In: *Proceedings of the Driving Simulation Conference, North America 2007 (DSC-NA 2007)* Ford Motor Company/National Highway Traffic Safety Administration/University of Iowa, Iowa City/Transportation Research Board.
- Kolich, M., 2008. A conceptual framework proposed to formalize the scientific investigation of automobile seat comfort. *Appl. Ergon.* **39** (1), 15–27.
- Koyano, M., Kimishima, T., Nakayama, K., 2003. Quantification of static seating comfort of motorcycle seats. *JSAE Rev.* **24** (1), 99.
- Ma'arof, M.I.N., Ahmad, I.N., 2012. Proposed standard method for motorcycle nomenclature system (Network of Ergonomics Societies Conference (SEANES)), 2012 Southeast Asian). IEEEE.
- Ma'arof, M.I.N., Omar, A.R., Haron, R., Husain, H. and Wahab, M.A., 2017. Muscular activities measurements of forward lean and upright sitting motorcycling postures via surface electromyography (sEMG). In: *Proceedings of the 8th International Conference on Mechanical and Manufacturing Engineering, ICME 2017, EDP Sciences*.
- Ma, T., Williamson, A., Friswell, R., 2003. A Pilot Study of Fatigue on Motorcycle Day Trips. Sydney-NSW Injury Risk Management Research Centre.
- Marina, M., Porta, J., Vallejo, L., Angulo, R., 2011. Monitoring hand flexor fatigue in a 24-h motorcycle endurance race. *J. Electromyogr. Kinesiol.* **21** (2), 255–261.
- Marina, M., Rios, M., Torrado, P., Busquets, A., Angulo-Barroso, R., 2015. Force-time course parameters and force fatigue model during an intermittent fatigue protocol in motorcycle race riders. *Scand. J. Med. Sci. Sport.* **25** (3), 406–416.
- Marina, M., Torrado, P., Busquets, A., Ríos, J., Angulo-Barroso, R., 2013. Comparison of an intermittent and continuous forearm muscles fatigue protocol with motorcycle riders and control group. *J. Electromyogr. Kinesiol.* **23** (1), 84–93.
- Matsumoto, T., Fukaya, Y., Yokomori, M., 1986. Effects of different weight loads on the body during motorcycle riding. *Scand. J. Work, Environ. Health* **12** (4 Spec No), 385–388.
- Matsumoto, T., Yokomori, M., Harada, N., 1982. Mailmen's vibration hazards induced by motorcycle riding. Results of cooling load tests. *Ind. Health* **20** (3), 167–175.
- McInally, S., 2003. R3-Riding strategy formulation model for risk adverse motorcyclists. *Contemp. Ergon.* 423–428.
- Mirbod, S., Yoshida, H., Jamali, M., Masamura, K., Inaba, R., Iwata, H., 1998. Assessment of hand-arm vibration exposure among traffic police motorcyclists. *J. Clin. Forensic Med.* **5** (1), 58.
- Mirbod, S.M., Inaba, R., Iwata, H., 1997a. Subjective symptoms among motorcycling traffic policemen. *Scand. J. Work, Environ. Health* **23** (1), 60–63.
- Mirbod, S.M., Yoshida, H., Jamali, M., Masamura, K., Inaba, R., Iwata, H., 1997b. Assessment of hand-arm vibration exposure among traffic police motorcyclists. *Int. Arch. Occup. Environ. Health* **70** (1), 22–28.
- Mizuno, Y., Yokoyama, K., Moyoshi, M., Takata, K., Okada, A., Hayano, J., 1996. Method to estimate the physical and mental workloads due to motorcycle riding using R-R interval variability of electrocardiogram. *Jpn. J. Med. Electron. Biol. Eng.* **34** (4), 7.
- Mizuno, Y., Yokoyama, K., Mukai, S., Hayano, J., Takata, K., 1998a. Estimation of subjective workload during motorcycle riding by logistic regression model with indices of heart rate variability. *Jpn. J. Med. Electron. Biol. Eng.* **36** (1), 1–6.
- Mizuno, Y., Yokoyama, K., Okada, A., Hayano, J., Takata, K., 1998b. Comparison of mental and physical workload from long-distance operations of automobile and motorcycle using ECG R-R intervals. *Jpn. J. Med. Electron. Biol. Eng.* **36** (2), 1.
- Mohamad, D., Deros, B.M., Indah Daruis, D.D., Khamis, N.K., Tahir, N.H.M., 2014. Assessment of hand-arm vibration exposure among motorcyclist in Malaysia. *Appl. Mech. Mater.* **663**, 395–399.
- Moher, D., Liberati, A., Tetzlaff, J., Altman, D.G., 2010. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Int. J. Surg.* **8** (5), 336–341.
- Moreno, R., Cardona, J., Pintado, P., Chicharro, J., 2011. Predictors of whole body vibration exposure in motorcycle riders. *Rev. Fac. De. Ing.* **61**, 93–103.
- Muslim, E., Moch, B.N., Puspasari, M.A., Siregar, R.A., 2015. Fatigue measurement of driving activity on male motorcycle drivers based on cognitive, physiological, and subjective approaches. *Int. J. Technol.* **6** (6), 976–982.
- Ohtsuka, R., Wang, Jian, Chihara, T., Yamanaka, K., Morishima, K., Daimoto, H., 2015. Estimation of mental workload during motorcycle operation. *Procedia Manuf.* **3**, 5313–5318.
- Ramasamy, S., Adalarasu, K., Patel, T.N., 2017. Evaluation of driving-related musculoskeletal disorders in motorbike riders using quick exposure check (QEC). *Biomed. Res.* **28** (5), 1962–1968.
- Rashid, H., Ma'arof, M.I.N., Haron, R., Fauzi, W.M.S.W., Omar, A.R., Jaafar, R., 2015. Selection of muscle groups for surface electromyography (sEMG) measurement in analyzing motorcycling activity. *J. Teknol.* **76** (7), 103–107.
- Rashid, H., Omar, A.R., Ahmad, I.N., Mohamed, Z., Fauzi, W.M.S.W., Mahmud, Z., Haron, R., 2016. Motorcyclists' prolonged riding simulation: the setup and procedures. *J. Mech. Eng.*
- Rashid, H., Omar, A.R., Jaafar, R., Abdullah, S.C., Ma'arof, M.I.N., Fauzi, W.M.S.W., Haron, R., Mahmud, Z., Shapie, M.A.M., Ismail, M.A.M., 2015. Usage of wireless Myon 320 surface electromyography (sEMG) system in recording motorcyclist muscle activities on real roads: a case study. *Procedia Manuf.* **3**, 2566–2573.

- Robertson, S., 1986. An Assessment of the Ergonomic Problems of Motorcyclists with Special Reference to the Riding Position and Seat Height (MSc Thesis). Loughborough University of Technology, UK.
- Robertson, S., Minter, A., 1996. A study of some anthropometric characteristics of motorcycle riders. *Appl. Ergon.* **27** (4), 223–229.
- Robertson, S., Porter, J., 1988. Motorcycle ergonomics: an exploratory study: robertson, S., and Porter, J.M. In: Megaw, E.D. (Ed.), *Contemporary Ergonomics 1987*. Taylor and Francis, London, pp. 173–178 (*Applied Ergonomics* 19(2): 160).
- Robertson, S., Stedmon, A., Bust, P., Stedmon, D., 2009. *MotorcycleErgonomics: Some Key Themes in Research* (Contemporary Ergonomics 2009: Proceedings of the International Conference on Contemporary Ergonomics 2009). CRC Press.
- Rodriguez, A.C., Barrero, L.H., 2017. Job rotation: effects on muscular activity variability. *Appl. Ergon.* **60**, 83–92.
- Roseiro, L.M., Neto, M.A., Amaro, A.M., Alcobia, C.J., Paulino, M.F., 2016. Hand-arm and whole-body vibrations induced in cross motorcycle and bicycle drivers. *Int. J. Ind. Ergon.* **56**, 150–160.
- Sai Praveen, V. and Ray, G., 2009. A study on Motorcycle usage and comfort in urban India. In: Proceedings of the 19th Triennial Congress of the IEA.
- Sai Praveen, V., Venkata Mangaraju, K., Venkatesh, G. and Babu, R., 2009. "Rider response time in motorcycle riding." SAE Technical Papers.
- Shafiei, U.K.M., Karuppiak, K., Timrin, S.B.M., Meng, G.Y., Rasdi, I., Alias, A.N., 2015. The effectiveness of new model of motorcycle seat with built-in lumbar support. *J. Teknol.* **77** (27), 97–103.
- Shahar, A., Poulter, D., Clarke, D., Crundall, D., 2010. Motorcyclists' and car drivers' responses to hazards. *Transp. Res. Part F: Traffic Psychol. Behav.* **13** (4), 243–254.
- Slavin, R.E., 1995. Best evidence synthesis: an intelligent alternative to meta-analysis. *J. Clin. Epidemiol.* **48** (1), 9–18.
- Smith, D.R., Andrews, D.M., Wawrow, P.T., 2006. Development and evaluation of the automotive seating discomfort questionnaire (ASDQ). *Int. J. Ind. Ergon.* **36** (2), 141–149.
- Smith, T., Zellner, J. and Rogers, N.M., 2006. A three dimensional analysis of riding posture on three different styles of motorcycle. In: Proceedings of the International Motorcycle Safety Conference-March.
- Stedmon, A., Hargreaves, S., Fitz-Gibbons, M. and Wood, C. (2008a). Different riders on different motorcycles: A quasi-experimental approach to rider comfort. In: Proceedings of the Annual Conference of the Ergonomics Society on Contemporary Ergonomics, Nottingham.
- Stedmon, A., Robertson, S., Yates, T., Fitzpatrick, B., 2008b. Profiling a new user group: anthropometric data for motorcyclists. *Contemp. Ergon.* **2008**, 779.
- Stedmon, A.W., 2007. Motorcycling is a pain in the neck, numb bum, aching wrists - Or all these things! A rider comfort survey. In: Proceedings of the Annual Conference of the Ergonomics Society on Contemporary Ergonomics, Nottingham.
- Stedmon, A.W., Brickell, E., Hancox, M., Noble, J., Rice, D., 2011. MotorcycleSim: a user-centred approach in developing a simulator for motorcycle ergonomics and rider human factors research. *Adv. Transp. Stud.* (27), 31–48.
- Stedmon, A.W., Hasseldine, B., Rice, D., Young, M., Markham, S., Hancox, M., Brickell, E., Noble, J., 2011. 'MotorcycleSim': an evaluation of rider interaction with an innovative motorcycle simulator. *Comput. J.* **54** (7), 1010–1025.
- Talib, M.F.M., Ma'Arof, M.I.N., Rashid, H., Ahmad, I.N., Syahmi, W.M., Fauzi, W., Omar, A.R., Jaafar, R., 2015. The explorations in defining motorcycling fatigue: a pilot study. *J. Teknol.* **76** (7), 115–118.
- Tanigaki, S., Kaneko, K., 1995. Seat comfort of motorcycle — fatigue reducing motorcycle seat using a newly developed shock absorbing material. *JSAE Rev.* **16** (3), 326.
- Torrado, P., Cabib, C., Morales, M., Valls-Sole, J., Marina, M., 2015. Neuromuscular fatigue after submaximal intermittent contractions in motorcycle riders. *Int. J. Sport. Med.* **36** (11), 922–928.
- Velagapudi, S.P., Balasubramanian, V., Adalarasu, K., Babu, R. and Mangaraju, V., 2010. "Muscle fatigue due to motorcycle riding." SAE Technical Papers.
- Velagapudi, S.P., Ray, G.G., 2017. Development of a seating comfort questionnaire for motorcycles. *Hum. Factors* **59** (8), 1249–1262.
- Walker, G.H., Stanton, N.A., Young, M.S., 2006. The ironies of vehicle feedback in car design. *Ergonomics* **49** (2), 161–179.
- WHO, W.H.O., 2015. *Global Status Report on Road Safety 2015*. World Health Organization.
- Williamson, A., Lombardi, D.A., Folkard, S., Stutts, J., Courtney, T.K., Connor, J.L., 2011. The link between fatigue and safety. *Accid. Anal. Prev.* **43** (2), 498–515.
- Williamson, A.M., Feyer, A.-M., Mattick, R.P., Friswell, R., Finlay-Brown, S., 2001. Developing measures of fatigue using an alcohol comparison to validate the effects of fatigue on performance. *Accid. Anal. Prev.* **33** (3), 313–326.
- Xu, Z., Zhang, Z., Zhou, K., Luo, C., Su, Z., 2007. Analysis and improvement of motorcycle vibration comfort. *Zhongguo Jixie Gongcheng/China Mech. Eng.* **18** (24), 3009–3013.
- Xu, Z.M., Yang, J.G., Zhang, Z.F., Li, S.S., Li, X.L., 2013. Multi-objective optimization for motorcycle suspension parameters based on parallel tasks under different conditions. *Zhendong yu Chongji/J. Vib. Shock* **32** (4), 59–65.
- Zhang, L., Helander, M.G., Drury, C.G., 1996. Identifying factors of comfort and discomfort in sitting. *Human. factors* **38** (3), 377–389.
- Zou, X., Xiong, F., Yuan, D., Yi, P., 2014. Virtual test method for motorcycle frame based on multi-axes road simulation using excitation spectrum. *Nongye Gongcheng Xuebao/Trans. Chin. Soc. Agric. Eng.* **30** (15), 39–45.