Standard Scientific Research and Essays Vol1 (12): 313-339, November 2013(ISSN: 2310-7502)
http://www.standresjournals.org/journals/SSRE

Research Article

Ergonomic design of Motor Bikes in Nigeria

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Accepted 16 November 2013

Abstract

Back pain is a frequently occurring complain in adults, having a relatively large impact on the Nigerian bike riders. Intervertebral disc are the key element of back pain. Prolonged exposure to sitting posture in bike riding can give rise to musculoskeletal disorders of the lower back. This study seeks to determine the level of prevalence of MSD among commercial motorbike riders in Nigeria and investigate its possible causes resulting from non-alignment between the rider's anthropometric characteristics and the motor bikes. Nigeria was divided into four zones and 2000 motor bike riders were selected and surveyed in each zone using body diagram in combination with questionnaire. A total of 8000 participants were considered. As a result of the survey, 40 participants from each zone were randomly selected and studied. Anthropometric measurements of the motor bike riders as well as the dimensions of the motor bikes were also taken and compared with the dimensions of the existing motor bikes. In addition, the characteristics angles of 9 body zones were determined. The survey shows that 79% of the bike riders have lower back pain; the anthropometric date showed that the existing motor bikes and the riders characteristics angles {θ1(head/Neck) = 144°, θ2(Elbow/Chest) = 37°, θ3(Elbow) = 139°, θ4(Waist/buttocks) = 167°, θ5(Waist/Laps) = 97° and θ6(Laps/Ankle = 76° respectively}. do not match which require the generation of an anthropometric data for Nigeria riders and their motor bikes for a redesign to Nigeria specification. The height of the human linkage representation is about 165cm hypothetically, and the characteristic angles for redesign to comfort are: {θ1(head/Neck) = 160°, θ2(Elbow/Chest) = 41°, θ3(Elbow) = 144°, θ4(Waist/buttocks) = 171°, θ5(Waist/Laps) = 102° and θ6(Laps/Ankle = 81° respectively}.The study identifies the problem of MSD among motorbike riders in Nigeria and their causes. The results of this study show the agreement between a questionnaire on MSD for the low back and other parts of the body. On this note, anthropometric data will be a resolution for a redesign due to the mismatch between Nigeria riders' characteristics angles and the motor bikes. The significant achievement of this research captured the presentation of an anthropometric data. There is a need for Nigerians anthropometric data in design of motor bikes to create a match between the riders and their motor bikes, after the evaluation of all other possible causes of MSD which can be made minimal with the implementation of the right anthropometric data for design.

Keywords: Anthropometric Data, Low Back Pain (LBP), Mosculoskeletal Disorder (MSD), Intervertebral Disc, Vibration, Body Map Diagram (BMD).

INTRODUCTION

The motivation for the continuous search to improve the comfort and health level in motorbikes riders exposed to whole-body vibrations is based on the large medical and economic cost involved in the occurrence of low back pain (Adams *et al.,* 2004). A clear link exists between low back pain and occupations involving vibration exposure. The direct link between whole-body vibrations and low back pain is however very weak and other stress factors as sustained sitting, posture and lifestyle might be of greater importance (Adams *et al.,* 1996).

Back pain is a frequently occurring complaint in motor bike riding, having a relatively large impact on the Nigerian economy due to the fact that it often partially incapacitates the patient. Intervertebral disc are believed to be a key element of back pain.

There is general agreement among researchers that work related musculoskeletal disorders (WMSD) arise from a combination of repetition, force, posture, individual and psychosocial factors. However, despite the widespread recognition of these primary risk factors, ergonomics interventions often only achieve limited success in changing work practice and reducing operator exposure to WMSD risks (Skov *et al.,* 1996).

Ergonomics is frequently able to identify elementary flaws in task and yet rectifying these obvious problems regularly proves to be difficult in practice. A growing body of research demonstrates that, despite the potential utility of ergonomics for workmen, all too rarely are guidance and recommendations actually implemented (Liker *et al.,* 1984; Urlings *et al.,* 1990; Herdrick, 1991; Alexander and Orr, 1999).

A number of studies have reported a high incidence of work-related musculoskeletal disorders, especially in the back, neck and shoulders, amongst workers of various disciplines (Grant *et al.,* 1995; Crawford and lane, 1998; Shimaoka *et al.,* 1998). Some risk factors are obvious, particularly for the motorbike riders who are more likely to sit on the vibrating locomotive bike for more than 10 hours daily as a means of livelihood. This resulted from a boost in the Nigeria international trade which benefited the transportation sector of the Nigeria economy in the 1980's when Nigeria experienced an industrial transformation. As a result of this trade, motor bikes were imported to the country as alternative means of transportation that collapsed the craftsmanship populace given rise to motor bike riding as the easiest means of livelihood by many Nigerians. This lucrative adventure has left a land mark on the health of many involved Nigerians thereby exposing them to musculoskeletal disorder such as lower back pain which is now categorically imperative (Pilot study).

Although sitting while driving is not equivalent to sedentary work, many experimental studies have investigated the link between a sitting posture and LBP. Early studies have indicated that sitting without lumbar support and a backrest could increase disk pressure (Nachemson, 1981).

Work-related musculoskeletal disorders, especially low back pain, cause substantial economic losses to individuals as well as to the community. Professional riders/drivers have been found to be at high risk for developing LBP due to prolonged sitting and bikes/vehicle vibration (Carrier *et al.,* 1992).

The factors of importance in seat design are both varied and interactive. Optimization in one area will often be at the expense of another. For example, it is possible to increase the comfort, or at least, decrease the discomfort associated with a seat for some users by contouring its shape during the upholstery. However, to do this is to render the seat less suitable for other users of a different somato type. Such contouring also increases the postural constraint imposed by the seat on the sitter. Therefore, it will be seen that no single factor can be used to determine the specification of work seat, and the importance of an approach which embraces many factors becomes clear.

On this note, the present study requires a redesign of the motor bike to reduce and further avoid lower back pain that results from the collapse of the inter- vertebral disc (slipped disc), by utilizing a detailed anthropometric data.

Concept of design has a major impact in defining the nature and amount of work required during the detailed design phase and other subsequent activities such as construction/manufacturing. When a design is poorly conceived, such design cannot be compensated for by a good detailed design since the design direction and possibly scope, will be laid down during the conceptual stage. In other words, the detailed design phase merely works within the scope defined during the conceptual stage.

Prolonged exposure to sitting posture in bike riding can give rise to musculoskeletal disorders of the lower back. Musculoskeletal disorders are the initial or secondary symptom of the lower back or waist disorders caused by vibration and posture of bike riders on motion, (Matoba, *et al.,* 1995). They are therefore important symptom for health surveillance.

One of the most popular survey tools for detecting musculoskeletal disorders is the Standardized Nordic Questionnaire (SNQ). The SNQ was developed by a team of Nordic researchers organized to create a simple standardized questionnaire that could be used for the screening of musculoskeletal disorders as a part of ergonomic programs and for epidemiological studies of musculoskeletal disorders (Kuorinka, *et al.,* 1987). But the SNQ is not yet widely used in Nigeria, particular in workers exposed to vibration and low back pain.

Anthropometric Data

Anthropometric data are used in design standards for new systems and in the evaluation of existing system in which there is a human equipment interface. The purpose of the data is to ensure that the rider(s) is/are comfortable and efficient in performing activities and in the use of equipment. (Waller *et al.,* 1997)

Traditionally, anthropometric data used by industrial designers has come from military studies (Eastman, 1983).

Because no comprehensive and current information on the civilian population is available, military data sets are the best possible estimate of presenting anthropometric data. However, military personnel do not present the extremes of height and weight body dimension of the population (Eastman, 1983; Gilmone *et al.,* 1997).

In the past, males dominate the industrial workforce. The industrial workforce of today comprises of both male and female between the ages of 25 and 70 who may have chronic illness and/or functional capacity losses. (Eastman, 1983; Waller *et al.,* 1997)

Ergonomic designs of workplaces and equipment must take into account the physical capabilities and characteristics of man/woman and the racially and ethnically diverse population. (Eastman, 1983; Waller *et al.,* 1997) where possible, however, anthropometric data for specific population should be used (Waller *et al.,* 1997). In a study conducted by the researcher of this work in May, 2010 of the mass transit bikes used in urban area in Nigeria, it was found that many of the motorbikes are designed and built in China (Pilot study). The design was based on the Chinese anthropometric data meant for the population of smaller people. The misapplication of anthropometric data resulted in an inappropriate and poor design for other consumers, with the workforce modifying the design or creating a back lean to accommodate their needs.

Bike Rider's Posture

Bike riding posture used by bike riders should take into consideration musculoskeletal and biomechanical factors, and ensure that all riding tasks are conducted within a comfortable reach range. The posture of the seated person is dependent on the design of the seat itself, individual seating habits and the work to be performed.

Seated postures are defined as the body posture in which the weight of the body is transferred to a supporting area- the ischial tuberosities of the pelvis and their surrounding soft tissues (Chaffin *et al.,* 1991).

The biomechanical considerations of seated postures include the spine, arms and legs. The muscles at the back of the thighs influence the relative position of the spine and pelvis. The location and scope of the work area influences the position of the neck, shoulders and upper extremities, when an individual is in a seated posture. Therefore, along with the seat itself, it is essential that the work to be performed be taken into consideration (Chaffin *et al.,* 1991; Gilmore *et al.,* 1997) Because of the factors that influence good posture; there is no single, ideal posture. No posture can be maintained indefinitely. This concept has been widely investigated and stressed by several investigators (Waller *et al.,* 1997). However, there are several factors which help to minimize musculoskeletal stresses. It is here noted for acceptance that

The seat should permit shifting or changing of a seat posture.

A large cushioned adjustable back support should be provided.

Seat surface should be accommodating but not spongy, in order to accommodate the forces transmitted on it.

Adjustments in seat height and angles be easy.

All of these features contribute to good seated posture. Additionally, providing a biomechanically improved seated workstation requires consideration of the size variation in the workforce population and that prolonged static muscle exertion is minimized to prevent muscle fatigue.

Vibration Overview

Vibration is oscillatory motion where the motion is not constant but alternately greater and less than some average value. The magnitude of the vibration is determined by the extent of oscillation, while the frequency is determined by the repetition rate of the cycles of oscillation.

Vibration is divided between deterministic and stochastic motions.

Deterministic vibration is that which can be predicted; stochastic vibration is a random motion. Both deterministic and stochastic vibration can be subdivided further. The deterministic class of oscillatory motion can be broken down into periodic, which is comprised of either sinusoidal or multi-sinusoidal, and non-periodic motion, which is comprised of transient motion and shock. Vibratory motion is periodic, and is usually expressed in hertz, the number of complete cycles in one second. In an occupational setting, workers on vehicles are nearly always exposed to stochastic whole-body vibration (WBV), which must be considered as broad-band vibration, i.e. 'vibration occurring in more than one-third-octave band' (ISO 1978 a) (Meister, 1984). The stochastic (or random) class of oscillatory motion can be broken down into stationary ergodic (which can be further subdivided into strongly self stationary and weakly self stationary), and non-stationary oscillatory motion (Griffith, 1990).

Vibratory motion of an object begins at some reference point and moves horizontally, vertically, or laterally when linear. This same object can also rotate in the form of pitch, yaw, and roll. To simplify analysis only linear motion is considered in human vibration (Wasserman, 1995). Objects subjected to vibration, frequently exhibit a phenomenon called resonance, which may damage or actually destroy the vibrating object (Wasserman, 1995). When an object is exposed to vibration and resonance occurs, the object experiencing the vibration will amplify or increase the peak signal, or magnitude of the vibration within the object.

The energy of the vibration is related to this peak; therefore a greater peak value indicates higher energy, possibly resulting in damage of the object. To further illustrate the concept of resonance, one can think of a tuning fork. When the tuning fork is brought near a vibrating string, which is not in the same key, nothing occurs. However, when the fork is placed close to a vibrating string in the same key, the fork begins to vibrate and the vibration in the form of sound is actually amplified. The tuning fork experiences resonance. Unfortunately, human beings are not exempted from experiencing this phenomenon at certain resonant frequencies. It is thought that the WBV resonance in the vertical direction is 4 to 8 Hz (nominally 5Hz) and in the horizontal and lateral directions WBV resonance thought to be between 1 to 2 Hz (Wasserman, 1996).

Vibration data have become a critical part of the design and engineering of new machines and process systems. Data derived from similar or existing machinery can be extrapolated to form the basis of a preliminary design. Prototype testing of new machinery and systems allows these preliminary designs to be finalized, and the vibration data from the testing adds to the design database.

The vibration which occurs in most machines, vehicles, structures, buildings and dynamic systems is undesirable, not only because of the resulting unpleasant motions and the dynamic stresses which may lead to fatigue and failure of the structure or machine, and the energy losses and reduction in performance which accompany vibrations, but also because of the noise produced. Noise is generally considered to be unwanted sound, and since sound is produced by some source of motion or vibration causing pressure changes which propagate through the air or other transmitting medium, vibration control is of fundamental importance to sound attenuation. Vibration analysis of machines and structures is therefore often a necessary prerequisite for controlling not only vibration but also noise.

Until early this century, machines and structures usually had very high mass and damping, because heavy beams, timbers, castings and stonework were used in their construction. Since the vibration excitation sources were often small in magnitude, the dynamic response of these highly damped machines was low. However, with the development of strong lightweight materials, increased knowledge of material properties and structural loading, and improved analysis and design techniques, the mass of machines and structures built to fulfill a particular function has decreased.

Furthermore, the efficiency and speed of machinery have increased so that the vibration exciting forces are higher, and dynamic systems often contain high energy sources which can create intense noise and vibration problems. This process of increasing excitation with reducing machine mass and damping has continued at an increasing rate to the present day when few, if any, machines can be designed without carrying out the necessary vibration analysis, if their dynamic performance is to be acceptable. The demands made on machinery, structures, and dynamic systems are also increasing, so that the dynamic performance requirements are always rising.

Automotive Seating

In the context of automotive seating, it is rather obvious that traditional lumbar support recommendations are failing the consumers. To combat this problem, new features are constantly being developed to address the muscle activity common in sitting postures. Massaging lumber mechanisms are an example. Backrest angle and lumbar support prominences are two factors that, independent of feature, affect the occupant.

Anderson *et al., (*1974*)* found that an increase in automobile seat backrest angle was accompanied by a decrease in myoelectric activity. The explanation is simple. When the backrest angle is increased, a larger proportion of the occupant's body mass is transferred to the backrest and thus the stress on the back musculature is reduced.

Even though the aforementioned rationale is fairly well understood, there is, to date, no universally accepted research that definitively outlines an optimal backrest angle. Vehicle package is, obviously, the limiting factor. More specifically, the backrest angle is restricted by the need for a good field of view. That is, the eyes must be suitably placed in relation to the automobile body so that vision is not obscured. When the backrest angle is too large, the head must be flexed to enable the driver to see the road.

The appropriate design of a lumber support, in terms of prominence, is one of the most widely discussed issues in the ergonomics of sitting. A lumber supper is the structure that contacts the lower back in the area of the lumber spine during sitting. In the traditional automotive seat, the lumber support is integrated into the backrest contour. The general purpose of the lumber support is to stabilize the occupant's torso and, thereby, improve postural stability. This is accomplished by restricting the rearward rotation of the pelvic that normally accompanies sitting while at the same time reduce flexion (forward bending) of the lumber spine. Rearward rotation leading to flexion causes the lumber spine to move from lordosis towards kyphosis.

Automobile seat designers have, for a long time, attempted to preserve or induce, to the extent possible, a lordotic spine curvature by providing a firm, longitudinally convex lumber support in lower part of the backrest. The deflected contour of such a support, based on general design practice, should mate with the lordosis of the occupant lower back providing relatively even contact pressure behind the pelvix and lumber spine. Conventional design wisdom states that if the design of the lumber contour does not induce lordosis, there is often, a mismatch between the occupants back and the seat. According to Reed *et al.*, (1991) this mismatch may produce uncomfortable pressure concentrations or a lack of support in the lower levels of the lumber spine (i.e the region where discomfort is most frequently reported). In addition to creating discomfort, it is also possible to infer that this mismatch may lead to increase muscle activity.

By the mid 1970s, most lumber support recommendations where strongly influenced by physiological studies of the load on the lumber spine. Anderson *et al* (1974) found the lowest level of myoelectric activity with an automobile seat lumber support prominence of 50mm. based on the assumption that low myoelectric activity is favorable; Anderson *et al* (1974) recommended a lumber support prominence of 50mm.

In view of this work, one might question the need for further research into lumber support design. However, some recent investigations have suggested that current lumber support recommendations based on physiological considerations do not adequately take into account the behaviour of the occupants in the driving environment (Reed *et al.*, 1991).

As an example, Porter and Norris (1987), noting that the lumber support specifications in the literature are based primarily on physiological rationales, constructed a wooden laboratory seat to compare the lumber support specifications recommended by Anderson *et al.,* (1974) with occupant preferences. Porter and Norris (1987) found that people preferred postures with substantially less lordosis (i.e, 20mm).

More drastically, more researchers have even question whether a lordotic lumber spine posture is desirable when seated. Adams and Huttoms (1985), argue that the advantages of a flexed spine posture outweigh the disadvantages. They cite increased transport of disc metabilites with changing pressure levels as a factor in favour of flexed postures. In summary, questions have started to surface regarding the role of lumber support in automotive seating.

With the quantity and quality of research done in the area of automobile seat backrest, the lack of consensus is surprising. This study was conducted with the purpose of attempting to establish, for a specific automobile package and experimental protocol, the most advantageous combination of backrest angle and lumber support prominence (assume that low myoelectric activity is favourable).

Ergonomics being the application of a body of knowledge (life sciences, physical sciences, engineering etc.) dealing with the interactions between man and the total working environment, such as atmosphere, heat, light and sound as well as tools and equipment of the work place, recognizes operational conflicts which are bound to occur during the interaction in these environments either between humans, human to the environment, human and tools, and humans and machine resulting to human physiological, biomechanical and psychophysical hazards. These conflicts pose challenges.

This research becomes imperative because, the present bike design/construction were produced without the use of the anthropometric data of the Nigerian consumers which may have resulted in the present endemic MSD noticed among the Nigeria bike riders (Pilot study).

Anthropometry for Design for Nigerians

Statistics from around the world show the proportion of adult in the population has been steadily increasing over the last decades. This trend in population change appears to be emerging in most economically developed countries.

There has been considerable work on the effect of ageing on functional capacity such as hearing, vision, and physical strength in general, motor and sensory system, and so forth, physical body dimensions, that is, anthropometry, have remained relatively untouched.

In this study attempts will be made to develop an anthropometrics data on motor bike rider’s population. At present there are no such population data on the anthropometric of motor bike riders in Nigeria. One of the objectives of the study was to collect data on reasonable number of body dimensions, which can be useful for the design of motor bikes for motor bike riders. It is expected that this study will provide help to designers, who have been unable to design specifically suited products for motor bike rider’s population due to lack for proper data.

METHODOLOGY

To investigate the verbal complaints of MSD, by the motorbike riders in Nigeria, Nigeria was divided into four zones and 2000 registered commercial motorbike/riders were selected from each zone for the preliminary study.

To study these 8000 selected participants, a team consisting of medical doctors, physiotherapist and research assistants were set up to carry out the study. Questionnaire was designed to be administered together with the use of localized body map diagram (BMD).
The result of the survey confirmed that there was prevalence of MSD among motorbike riders in Nigeria. For example, 7,134 or 89.2% of the participants complain of pain in the lower back which led to the need for more detailed study.

Detailed Study

The result of the above initial study necessitated the need for detailed study to find out what parts of the body are affected and why. Forty participants were randomly selected among the motorbike riders in each zone for the more detailed study with special consideration to available resources and manpower to undertake the research. These forty participants constitute 2% of the original sample of 2000 participants from each zone. Their age ranges between 20 and 60 years with mean of 35 years. Their years of experience were between 4 and 24 years.

The general questionnaire included a body map diagram that was pictorially explicit in getting details about the presence of physical aches, pain, discomfort etc., for the past 12 months and past 7 days in each of the body areas. It also included grades of severity by using measure of function status: “Have you at any time during the last 12 months been prevented from doing your normal work because of the trouble?” All answers were in the form of a dichotomous Yes/No. The questionnaire is in the appendix. Because of high percentage of bike riders experiencing MSD (89.2%), it was speculated that anthropometric characteristics of the riders and measurement of their workstations (motor cycle dimensions) may be necessary.

Anthropometric Measurement

Anthropometric characteristics of the 160 selected participants were measured. All participants had no physical disability and adverse health condition apart from MSD.

Participants were informed before the start of data collection the objective of the study. The procedure of measurements was explained in detail to them. It took 20 minutes to complete all the measurements set out in the study for each participant. Participants were allowed rest in between measurements if needed. Measurements were made with participants wearing light clothing and with bare feet.

It was speculated that apart from stature, there may be other anthropometric factors affecting comfort and discomfort among bike riders. Other ones considered are highlighted in table a. To eliminate inter observer variations, all measurements were made by the same person for all the participants.

The measurements made in the trial runs were cross-checked by the researcher to determine the accuracy and consistency of the measurements.

Table a. List of Anthropometric Dimensions selected for Measurement (Highlighted)

Dimension Number	Measure
1	Age
2	Weight
3	**Stature**
4	Eye height
5	Shoulder height
6	Elbow height
7	**Sitting height**
8	Sitting eye height
9	Sitting shoulder height
10	Sitting elbow height
11	Thigh thickness (thigh clearance)
12	**Buttock-knee length**
13	**Buttock-popliteal length**
14	**Knee height**
15	**Popliteal height**
16	Shoulder breadth (bideltoid)
17	Hip breadth
18	Ghest (bust) depth
19	Elbow-fingertip length
20	**Uper limb length**
21	Shoulder grip length
22	Hand length
23	Hand breadth

Measuring Instruments

The measuring equipment for anthropometric data collection consisted of a standard professional anthropometer, a weighting scale, and an adjustable chair. The measuring kit consisted of instruments for measurements of distances in straight lines, curves, circumferences, and thickness. The adjustable chair had a flat wooden seat with a high back rest. The seat and the backrest were aligned at right angles to each other and the seat acted as reference point for the measurements in the sitting position.

Riding Posture

Riding posture could be a major problem cumulating in riding discomfort. This riding posture could be as a result of non-alignment between the rider's anthropometric characteristics and the motor bikes.

The 160 subjects riding postures were investigated. To identify the magnitude and intensity of the perceived uncomfortable positions and the main uncomfortable causes concerning riders' riding postures, experimental measurements combined with questionnaire were used. Data were collected on their riding styles, riding postures were observed and level of discomfort resulting from the postures recorded as explained by the participants.

Riding Posture Measurement

To measure the characteristics points and angles of the subjects' riding postures, a 2D anthropometer was used which consists of rails, a sliding base, a rod-stick, a slide, meter rulers, and a laser pointer. As shown in Figure 1, the sliding base is put on the rails for X-axis movement and so does the slide on the rod-stick for Y-axis'. A laser pointer is fixed horizontally upon the slide connected with a bolt to screw onto the rod-stick, and two meter rules are adhered to the rails and the rod-stick in order to indicate the coordinate values of X-axis and Y-axis respectively. For a more precise measurement, all the parts were regulated and standardized before the performance including the perpendicularity of the rod-stick, the horizontal precision of the laser pointer, and the orientation of the coordinate origin for this measuring system. A SYM X'PRO 100 c.c. motor bike used as the anthropometric platform was then fixed parallel with the rails.

As shown in Figure 2 , a spatial measuring system of the human body consisting of three inter perpendicular axes can be expressed by the following planes: (1) the frontal plane (Y-Z Plane), tangential to the vertical plane of the seat back, (2) the sagittal-median plane (X-Z Plane), and (3) the transverse plane (Y-X Plane), crossing the acromion points. The intersection of these planes marks the origin of the polar co-ordinate axes of the measuring system (Nowak, 1996). From the view on the frontal plane, both sides of the human body are essentially symmetrical based on the marked origin. Besides, the breadths of shoulder and hip and the widths between the corresponding pair of joints of elbows, wrists, knees, and ankles can be considered approximately equal and parallel while a rider is riding a motor bike. Using the constructed 2D anthropometer with the laser point to locate the nine characteristics points respectively, the coordinate parameters of these characteristic points can be measured.

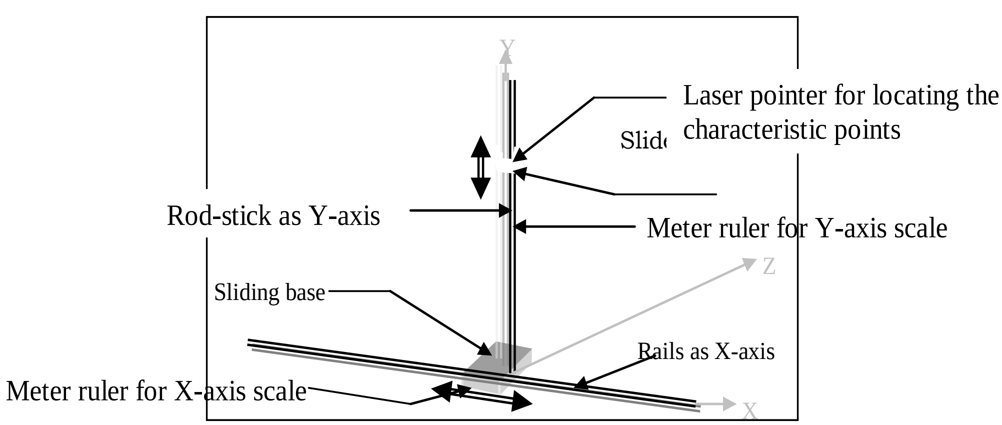


Figure1. Diagram of the 2D anthropometer for the anthropometric measurement

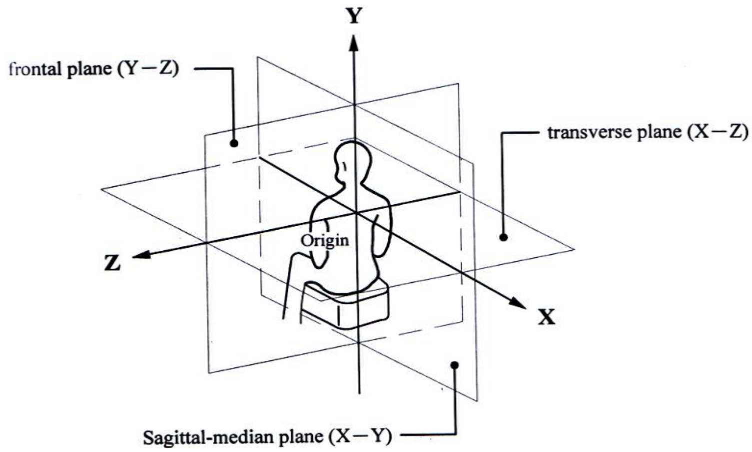


Figure 2. Diagram of the spatial measuring system for human body in a sitting posture

Riding Discomfort and Riding Postures

The purpose of this experimental study is to analyze the riding posture of motor bike riders and establish the correlations between riding uncomfortable factors (for existing motor bike) and riders' riding posture. Data were obtained on subjects' postures and riding experiences, the perceived uncomfortable positions and the main uncomfortable causes, and the characteristic angles of riding postures. To analyze these data, correlations were investigated and the grey relational model (Hertzberg, 1972) was employed to analyze the grey relational grades between the main uncomfortable causes and the subjects' statures, and those between the main uncomfortable causes and subjects' riding experiences in terms of the corresponding percentages of subjects' perceived uncomfortable positions. The grey relational analysis will help in understanding which ranges of riders' stature and which of riders' riding experiences are more relevant to main uncomfortable causes. Besides, by analyzing percentage distribution of the perceived uncomfortable positions with the corresponding characteristic angles of riding postures, we can estimate the weighted average of the characteristics angles as well as derive a set of suggested characteristic angles accepted by all the stature ranges of motor bike riders in Nigeria.

These suggested characteristic angles can be used as reference data for a motor bike design.

The Correlations between Riding Uncomfortable Factors and Riders' Riding Conditions

The correlations between riding uncomfortable factors and riders' riding conditions are significant anthropometric characteristics of motor bike riders. According to the study, the percentage of the riding uncomfortable factors are investigated through the questionnaire and data collected on the following.

(1) The percentages of participants who perceived uncomfortable positions at points "a" to "i".

(2) The percentages of participants who identify main uncomfortable causes as: the location of handlebar, the location of seat, the location of footrest, and the space of footrest at the point "a" to "i".

(3) The data were then summarized to show the relationship between the main uncomfortable cause and the perceived uncomfortable points in the body.

He summarized date were then converted to grey relationship model, normalized and converted to matrix equation. This would then represent the correlation between the main uncomfortable causes and the perceived uncomfortable points.

Riding Angle

Using the articulated linkage representation of the riders, the dimensions of the riding postures including the angles were then recorded. Six angles identified on the articulated linkage representation are θ_1 to θ_6. (See figure 3 below of linkage diagram). Each subject's sex, stature and their riding posture angles were recorded. Since these were uncomfortable riding angles, imposed on them by their workstation, there was need to find the riding postures in which the 95^0 percentile of the riders were comfortable.

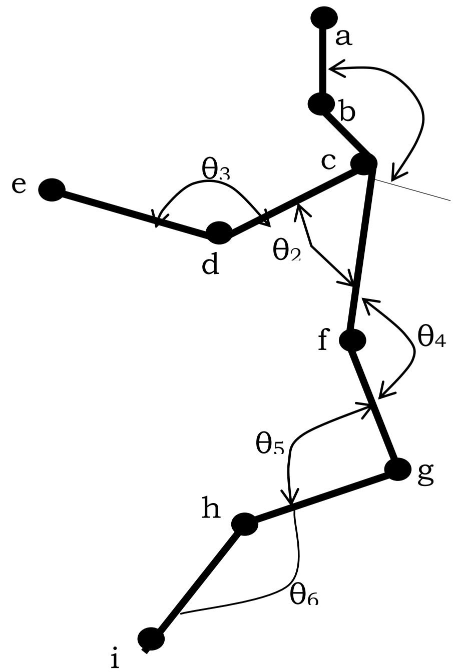


Figure 3. Diagram of the characteristics angles for anthropometric measurement. Hertzberg, (1972)

Data Collection for Design of Riding Comfortable Posture

Having studied the riding postures of the riders and their indication that the postures were not comfortable for them, there was need to experiment to modify the work station (motorbike) so that comfortable riding postures that will reduce incidents of MSD among them could be designed.

To do this, ironic model was constructed and placed against the existing motorbike. The comfortable riding angles were then measured for the 160 subjects. A new articulated linkage of the average rider (95^0 percentile of the riders) were then constructed and compared with the articulated linkage representation of the existing motor bike rider: Grey relationship models are then designed from the locations of comfortable positions of footrest, footrest space, handlebar and location of the seat, the four (4) areas of the motor bike where their locations makes the rider comfortable.

Using SPSS, the correlation between comfortable causes and perceived comfortable points were normalized and computed

The Correlations between Riding Comfortable Factors (Proposed Motor Bike) and Riders' Riding Conditions

The analysis of the study shows that the dimensions of the existing motor bikes do not match the anthropometric characteristics of the riders, the riders indicated their uncomfortable riding posture which were then measured and also indicated their uncomfortable positions. It was assured that the imposed riding postures by the riders workstations was due to miss-match between their anthropometric characteristics and the location and dimensions of the workstations (Motorbikes)

Therefore, to design a workstation that will be comfortable for the bike riders, their anthropometric characteristics were measured and the data used in designing comfortable work station for the riders.

Data were analyzed using SPSS/PC + (Norusis, 1990). The program was used first to check accuracy of entries by checking on outline and then for the statistical analysis. One participant (out of 161) was dropped as there were more than two extreme body dimensions associated with the participant**.**

A total of 160 participants were evaluated in the study. In the study sample, most of the participants (over 70%) were born in Nigeria, with about 9% mixed citizens by birth, 7% acquired citizens, and the rest from various parts of the country. This mix, incidentally, roughly represents the currents overall population distribution in Nigeria

The descriptive statistics for participants respectively were computed showing the mean (M), standard deviation (SD), median, range and coefficient of variation (CV) of the measured body dimensions. Percentile values for the body dimensions of the participants were also computed.

The work stations dimensions are constant. It is this workstation that imposes the postures on the riders. This gives rise to the need for the range of measurements or dimensions of workstation (Motor bikes) that will accommodate 95% of the motor bike riders as against 5% of the negligible non conformity population. Due to the considered anthropometric characteristics angles imposed on the riders by various heights of riders, the average height was used as the design consideration to represent a reasonable percentage of the motor bike riders in Nigeria. The percentages of the riding comfortable factors for the proposed motor bikes will be designed to fit the riding population.

Anthropometric Measurements of Participants

The Characteristic Angles of Riding Postures

Riding postures are more relevant to riders' statures. They are one of the important ergonomic problems in anthropometry for motor bike riders. In postures modeling, it is often desirable to describe body motion in terms of angles formed by body segments rather than attempting to model the coordinates of the joints directly (Faraway *et al.,* 1999). According to the experimental method, nine characteristic points per subject regarded as the perceived uncomfortable positions of riding postures were determined. Coordinate points as the independent variables (IVs) were measured using the 2D anthropometer in order to solve the dependent variables (DVs) of the characteristic angles. Substituting these measured coordinate data into Formula (3.1) respectively, the characteristic angles of motor bike riding postures in terms of each individual subject were obtained.

Anthropometric Data and Riders Work station

Apart from stature, the following anthropometric data are relevant for workstation (motor bike) design: Sitting height; Buttock-knee height; Buttock-popliteal length; Knee height and Popliteal height.

Based on the anthropometric results, constructed articulated linkage representation of the human skeletal system to specify the physical dimensions of the existing and proposed motor bike will be constructed. The height of the human linkage representation is about 165 cm hypothetically, and the characteristic angles are also determined. These angles are determined according to the ranges of the suggested angles of riding postures for motor bike riders in Nigeria.

Comparism between Existing and Proposed Work station

The human linkage representation is placed on the basic frame of the motor bike, so as to help specify the relative positions as well as to determine the key dimensions of the motor bike design. The positions of **Point e, Point g, and Point i** are very important in this diagram on figure 3, since they can be regarded as the contact points between the rider and the motorbike. Moreover, the three points are more relevant to appearance design of the motor bike, and they can be used to determine the location of handlebar, the location of seat, the location of footrest-board, and the space of footrest-board. That is an essential improvement in riding comfortable requirements.

A test run using back position for riders that will prove satisfactory for ergonomic parameters of adjustability, stability, solidity, durability and safety from various design concepts and criteria will be selected for the design.

Therefore, it is important to evaluate comfort ratings, adjustability, stability, solidity, durability and safety by conducting test on actual user group (Jung, 2005).

RESULT

The initial survey of 2000 participants from the North, South, East and Western Nigeria reported the prevalence of MSD in motor-bike riders as reported in Table 1 where the Southern Nigeria typically has a longer exposure time to work than those in other parts of the country, both in public and private riders.

Table 1. Prevalence of Musculoskeletal Disorder among Motorbike Riders. (Initial Survey)

Body parts	N (n=2000)	S (n=2000)	E(n=2000)	W(n=2000)
Neck Pain	111 (5.55)	123 (6.15)	98 (4.9)	101 (5.0)
Upper back pain	121 (6.05)	154 (7.7)	98 (4.9)	122 (6.1)
Lower back pain	**1,989 (99.45)**	**1,994 (99.7)**	**1,653 (82.6)**	**1,498 (74.9)**
Waist pain	1,487 (74.35)	1,477 (73.8)	1,239 (61.9)	1,364 (68.2)
Spinal cord pain	564 (28.2)	769 (38.4)	899 (44.9)	979 (48.9)
Eye pain	1,008 (50.4)	987 (49.3)	1,122 (56.1)	863 (43.1)
Hips/thighs pain	330 (16.5)	435 (21.7)	567 (28.3)	356 (17.8)
Knees	342 (17.1)	343 (17.1)	445 (22.2)	344 (17.2)
Chest pain	211 (10.5)	237 (11.8)	333 (16.6)	542 (27.1)

Note: Percentage (%) given in parentheses. N(North), S(South), E(East), W(West)

Analysis of Responses to Questionnaire

The results of the above prevalence's in MSD's in motor bike riders from the initial survey/study necessitated the need for detailed study. Forty participants (2%) were therefore randomly selected among the 2000 motorbike riders in each zone initially used for survey for the more detailed study. Their age ranges between 20 and 60 years with mean of 35 years.

These findings are of concern to the researcher, in that, the motor-bike producers should take sample of a country's anthropometric data before embarking on production for any consumer and both are receptive to ideas on how they might prevent and alleviate such symptoms. table2

As a result of the prevalence of MSD, it became imperative to generate data for conceived idea of improving the motor bike work station thereby giving room for an anthropometric data for Nigeria motor bike riders due to operational conflict detected between man and machine as experienced in Nigeria motor bike riders and their work station. Table3

Table 2. Prevalence of Musculoskeletal Disorder among Motorbike Riders by Questionnaire on Body Parts. (N=40)

Body parts	N (n=40)	S (n=40)	E(n=40)	W(n=40)
Neck Pain	2.20 (5.55)	2.46 (6.15)	1.96 (4.9)	2.00 (5.0)
Upper back pain	2.42 (6.05)	3.08 (7.7)	1.96 (4.9)	2.44 (6.1)
Lower back pain	**39.78 (99.45)**	**39.88 (99.7)**	**33.04 (82.6)**	**29.96 (74.9)**
Waist pain	29.74 (74.35)	29.52 (73.8)	24.76 (61.9)	27.28 (68.2)
Spinal cord pain	11.28 (28.2)	15.36 (38.4)	17.69 (44.9)	19.56 (48.9)
Eye pain	20.16 (50.4)	18.52 (49.3)	22.44 (56.1)	17.24 (43.1)
Hips/thighs pain	6.60 (16.5)	8.68 (21.7)	11.32 (28.3)	7.12 (17.8)
Knees	6.84 (17.1)	6.86 (17.1)	8.88 (22.2)	6.88 (17.2)
Chest pain	4.20 (10.5)	4.72 (11.8)	6.64 (16.6)	10.84 (27.1)

Note: Percentage (%) given in parentheses. N(North), S(South), E(East), W(West)

Table 3. Prevalence of Pain in Motorbike Riders Regional Frequencies

Body parts	N (n=40)	S(n=40)	E(n=40)	W(n=40)
Neck	1(2.5)	2(5)	1(2.5)	2(5)
Shoulder	5(12.5)**	5(12.5)	2(5)	4(10)
Elbow	7(17.5)*	7(17.5)	5(12.5)	3(7.5)
Wrist/Hands	5(12.5)	2(5)	2(5)	5(12.5)
Upper back	0(0)	0(0)	0(0)	3(7.5)
Lower back	7(17.5)	9(22.5)	7(17.5)	7(17.5)
Hips/thighs	0(0)	0(0)	0(0)	2(5)
Knees	2(5)	2(5)	2(5)	3(7.5)
Ankles/feet	1(2.5)	1(2.5)	2(5)	2(5)

Percentage (%) given in parentheses. **p<0.01, *p<0.05

The Correlations between Riding Uncomfortable Factors and Riders' Riding Conditions

The correlations between riding uncomfortable factors and riders' riding conditions are significant anthropometric characteristics of motor bike riders. According to the study, the percentage of the riding uncomfortable factors are investigated through the questionnaire and data collected on the following.

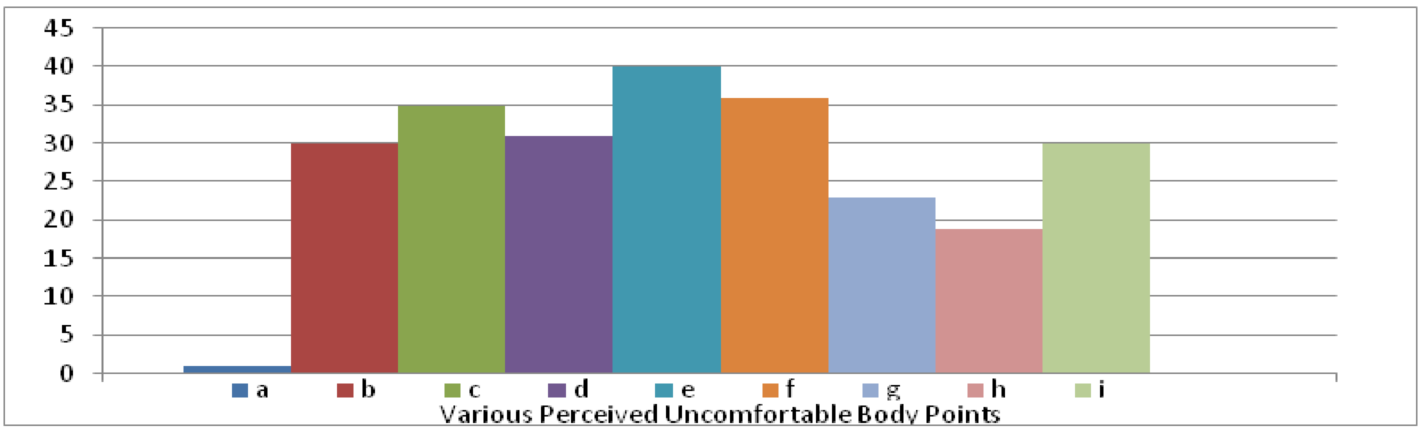
(1) The percentages of participants who perceived uncomfortable positions at points "a" to "i".

(2) The percentages of participants who identify main uncomfortable causes as: the location of handlebar, the location of seat, the location of footrest, and the space of footrest at the point "a" to "i".

(3) The data were then summarized to show the relationship between the main uncomfortable cause and the perceived uncomfortable points in the body.

The summarized data were then converted to grey relationship model, normalized and converted to matrix equation. This would then represent the correlation between the main uncomfortable causes and the perceived uncomfortable points. **4.1a, 4.1b, 4.1c, 4.1d, 4.2**

Used as reference sequences for the grey relational model, the statistical data are normalized and converted into a matrix shown in Equation (x), which represents the correlation between the main uncomfortable causes and the perceived uncomfortable points.



Figre 4.1a. The Location of Handle bar (C1)

Key:

Y-axis %	**Percentages of participants who perceived uncomfortable positions**
X-axis	Various Perceived Uncomfortable Body Points

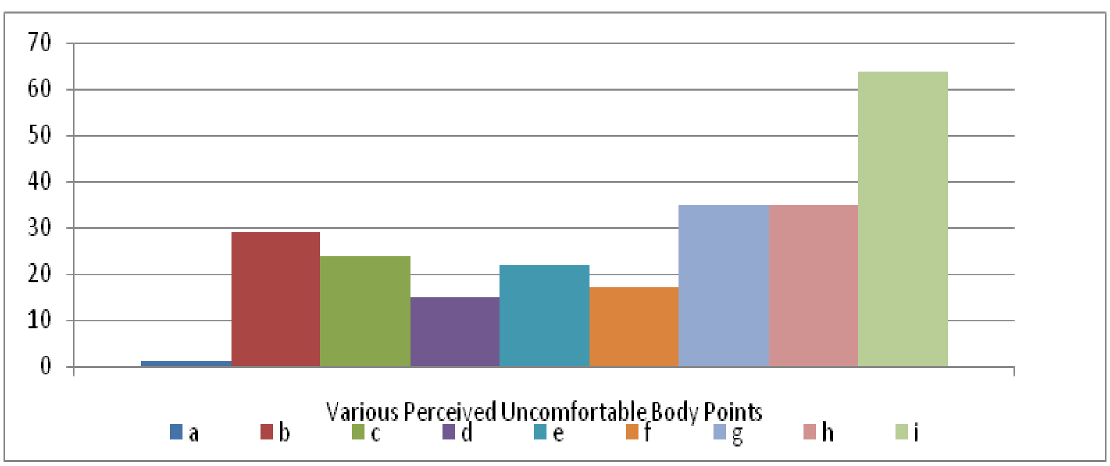


Figure 4.1b. The Location of Seat (C2)

Key:

Y-axis %	**Percentages of participants who perceived uncomfortable positions**
X-axis	Various Perceived Uncomfortable Body Points

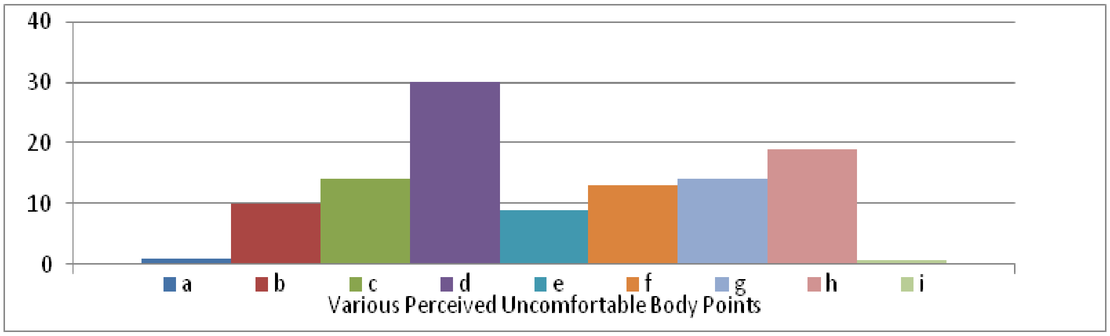


Figure 4.1c. The Location of Foot Rest (C3)

Key:

Y-axis %	**Percentages of participants who perceived uncomfortable positions**
X-axis	Various Perceived Uncomfortable Body Points

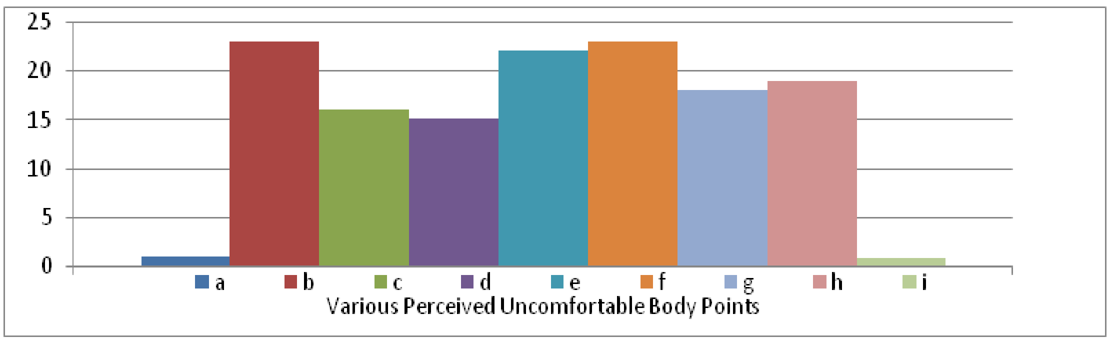
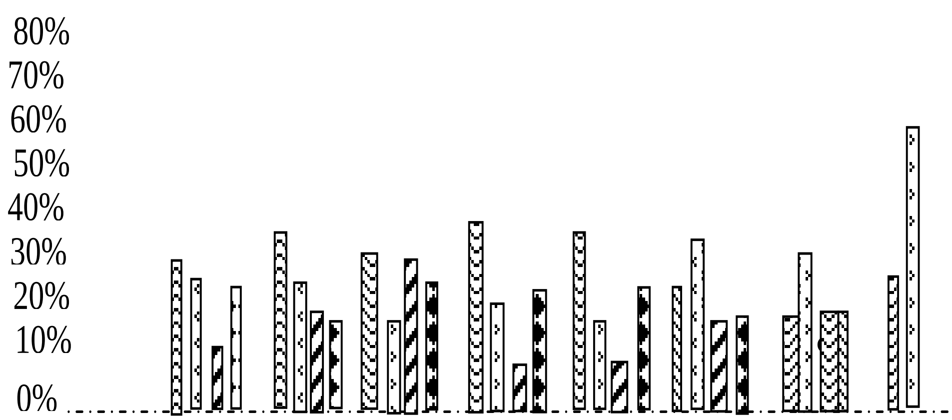


Figure 4.1d. **The Space of Footrest (C4)**

Key:

Y-axis %	**Percentages of participants who perceived uncomfortable positions**
X-axis	Various Perceived Uncomfortable Body Points



Causes ↓		Positions → a	b	c	d	e	f	g	h	i
The location of handlebar	(C1)	1%	30%	35%	31%	40%	37%	25%	19%	30%
The location of seat	(C2)	0.1%	29%	23%	17%	21%	18%	35%	35%	62%
The location of footrest	(C3)	0.2%	10%	18%	30%	09%	13%	14%	19%	0.2%
The space of footrest	(C4)	0.3%	23%	16%	22%	23%	24%	18%	19%	0.2%

Figure 4.2. Summary of fig 4.1 (a, b, c, d) of the Relationship between the Main Uncomfortable Causes and the Perceived Uncomfortable Points in the body (Existing Motor Bikes)

$$M_{\text{Causes-Positions}} = \left[x_o\,(c_m)\right]_{m \times n} = \begin{pmatrix} x_o\,(c_1) \\ x_o\,(c_2) \\ x_o\,(c_3) \\ x_o\,(c_4) \end{pmatrix}_{4\times 9}$$

$$= \begin{pmatrix} 0.000, 0.100, 0.120, 0.110, 0.140, 0.130, 0.080, & 0.060, 0.110 \\ 0.000, 0.100, 0.050, 0.050, 0.080, 0.050, 0.130, & 0.130, 0.240 \\ 0.000, 0.080, 0.120, 0.250, 0.050, 0.100, 0.110, & 0.150, 0.000 \\ 0.000, 0.140, 0.150, 0.080, 0.130, 0.140, 0.110, & 0.110, 0.000 \end{pmatrix} \quad (x)$$

Where

x_o (c_1) represents a reference sequence concerning the uncomfortable riding position caused by the location of handlebar:

x_o (c_2) represents a reference sequence concerning the uncomfortable riding position caused by the location of seat;

x_o (c_3) represents a reference sequence concerning the uncomfortable riding position caused by the location of footrest;

x_o (c_4) represents a reference sequence concerning the uncomfortable riding position caused by the space of footrest.

The Correlations between Riding Comfortable Factors (Proposed Motor Bike) and Riders' Riding Conditions

Existing motor bikes do not conform to the dimensions of the users in Nigeria as established in the articulated linkage above which will create the need for redesigning motor bikes for Nigeria users based on the anthropometric data generated. This is as a result of non-alignment between the rider's anthropometric characteristics and the motor bikes.

The results of the anthropometric measurements of the bike riders in discomfort zones are in tables 4 and 5 below. This study has attempted to collect and analyze anthropometric characteristics of motor bike riders in Nigeria. The objective was to fill in the gap information on anthropometric characteristics angle measurements needed to design motor bike for Nigeria riders.

Stature is one of the most important anthropometric characteristics affected by riders. Differences can be noticed in the stature of Nigerian motor bike riders when compared with those of British population. American populations are taller than the rest of the population. Data on British population are taken from ICE (1983), Dutch data from Molenbroek (1987), and American data from Stoudt (1981).

Table 4. Descriptive Statistics of Anthropometric Measurements of Motor Bike Riders in Nigeria (n= 160)

S/n	Description	M	SD	Median	Range	CV (%)
1	Stature	1658	79	1650	1491 - 1824	4.8
2	Sitting height	843	56	843	723 – 989	6.7
3	Buttock- knee length	549	38	547	443 – 610	6.9
4	Buttock-popliteal length	452	38	450	357 – 560	8.4
5	Knee height	515	31	513	462 – 580	6.0
6	Popliteal height	416	25	421	372 – 468	6.1
7	Upper limb length	782	74	789	677 – 987	9.4

Note. All linear dimensions are in mm CV- coefficient of variation

Table 5.Percentile Values (P) of Anthropometric Measurements of Motor Bike Riders in Nigeria. (n=160)

S/N	Dimension	P5	P25	P50	P75	P95
1	Stature	1518	1603	1650	1695	1816
2	Sitting eye height	632	693	732	766	799
3	Buttock-popliteal length	373	432	450	467	524
4	Knee height	470	486	513	539	570
5	Popliteal height	373	392	421	437	460
6	Shoulder breadth	342	367	395	415	453
7	Shoulder –grip length	412	647	689	746	811

Notes. All linear dimension are in, mm

Comfortable Body Points and Location of Motorbike Parts

The percentages of the riding comfortable factors for the proposed motor bikes due to the investigation done on existing motor bikes in Nigeria are as follows in figure 4.3 (a, b, c, d)

1 The percentages of participants who perceived uncomfortable positions at points "a" to "i".

2 The percentages of participants who identify main uncomfortable causes as: the location of handlebar, the location of seat, the location of footrest, and the space of footrest at the point "a" to "i".

3 The data were then summarized to show the relationship between the main uncomfortable cause and the perceived uncomfortable points

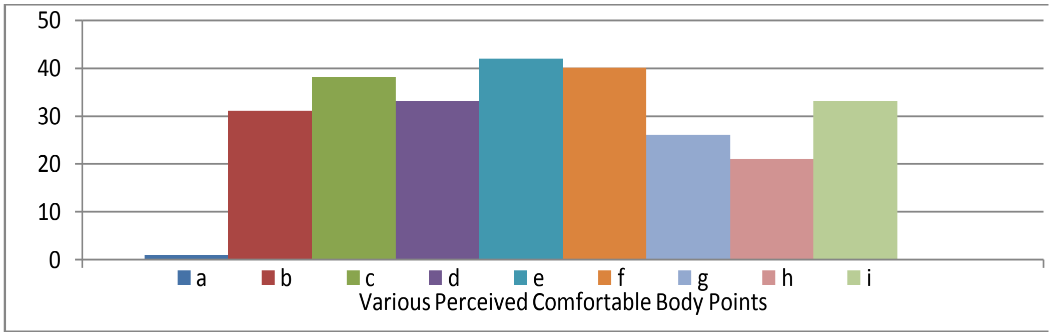


Figure 4.3a. The Location of Handle bar (C1)

Key:

Yaxis %	Percentages of Participants who Perceived Comfortable Positions
Xaxis	Various Perceived Comfortable Body Points

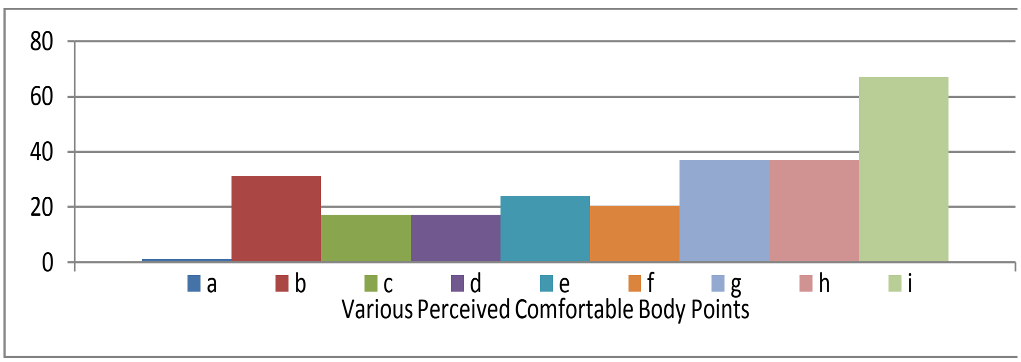


Figure 4.3b. The Location of Seat (C2)

Key:

Yaxis %	Percentages of Participants who Perceived Comfortable Positions
Xaxis	Various Perceived Comfortable Body Points

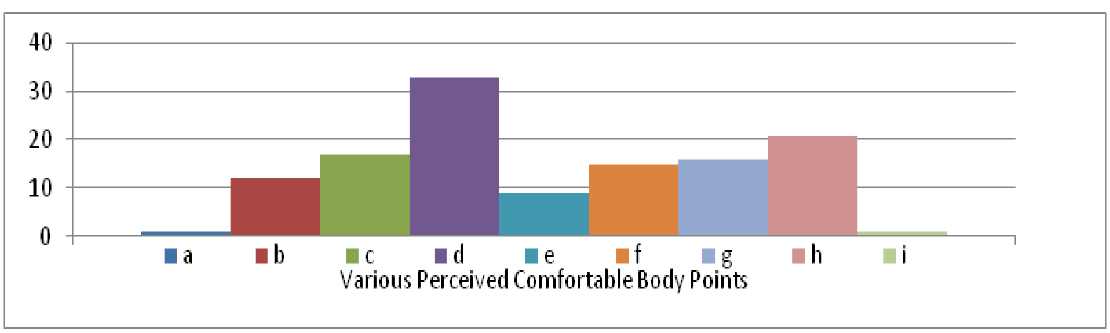
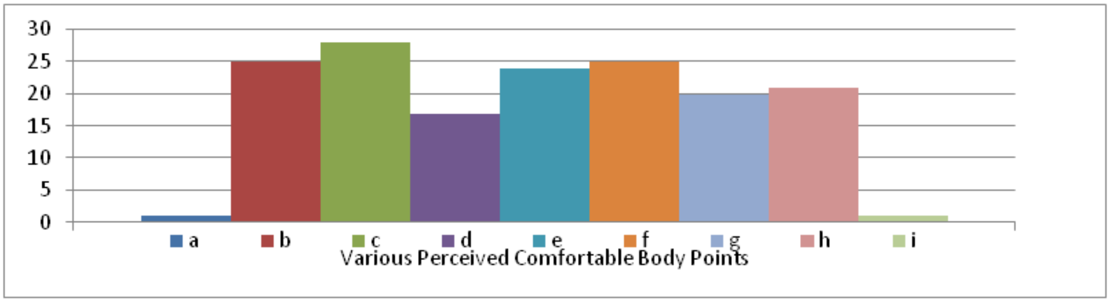


Figure 4.3c. The Location of Foot Rest (C3)

Key:

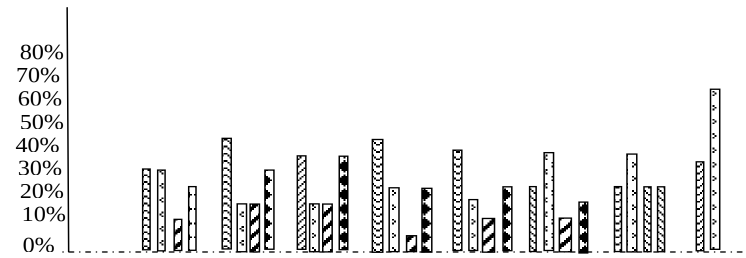
Yaxis %	**Percentages of Participants who Perceived Comfortable Positions**
Xaxis	Various Perceived Comfortable Body Points



Key:

Yaxis %	**Percentages of Participants who Perceived Comfortable Positions**
Xaxis	Various Perceived Comfortable Body Points

Figure 4.3d. The Space of Footrest (C4)

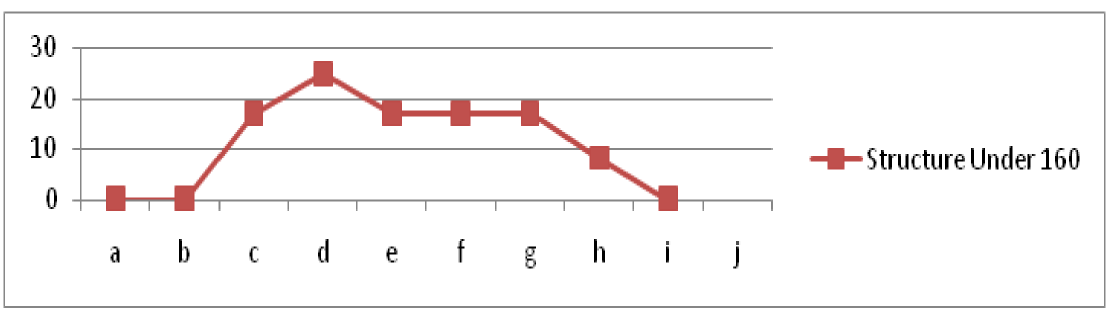


Causes ↓		Positions → a	b	c	d	e	f	g	h	i
The location of handlebar	(C1)	0%	31%	38%	33%	42%	40%	26%	21%	33%
The location of seat	(C2)	0%	31%	17%	17%	24%	20%	37%	37%	67%
The location of footrest	(C3)	0%	12%	17%	33%	9%	15%	16%	21%	0%
The space of footrest	(C4)	0%	25%	28%	17%	24%	25%	20%	21%	0%

Figure 4.4. Summary of figure 4.4 (a, b, c, d) of the Relationship between the Main Comfortable Causes and the Perceived Comfortable Points in the body (Proposed bikes)

Riding Posture and Riding Experience Influence on Discomfort

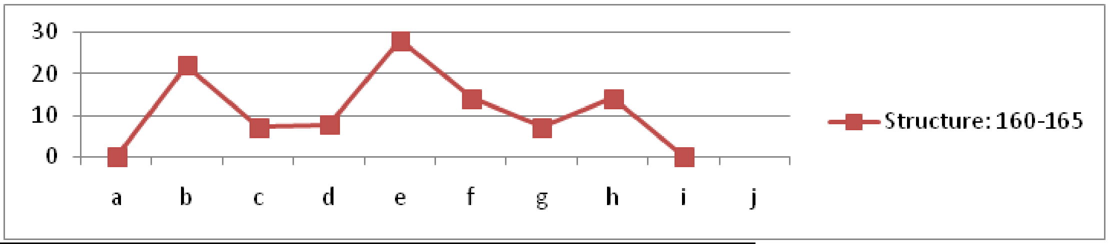
It was observed that the variables of riders' posture and riding experiences are major conditions influencing the comfort of motor bike riders in this study. Four ranges of riders' statures: under 160cm, 160cm to 165cm, 165cm to 175cm, and over 175cm as in Figure 4.5 (a, b, c, d) and four ranges of riders' riding experiences: under I year, I year to 2 years, 2 years to 3 years and over 3 years were determined Figure 4.7(a, b, c, d) as the riders' riding conditions to analyze the correlations between the two influencing conditions and the perceived comfortable positions. The correlations are classified as shown in Figure 4.6 and Figure 4.8 respectively.



X-Axis	Subject Structure Under 160 cm (S1)
Y-Axis %	Perceived Comfortable Body Points

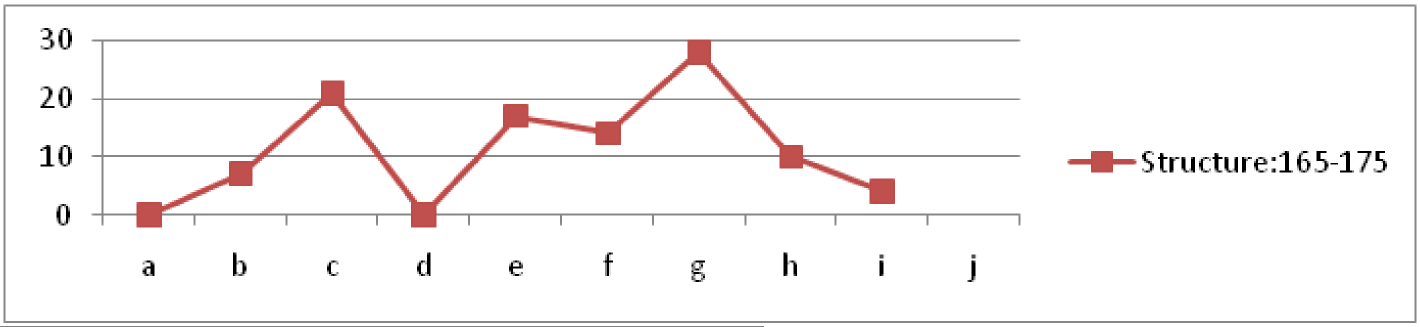
Figure 4.5a. Subject Structure Under 160 cm (S1)

The statistical data of Figure 4.6 and Figure 4.8 are used as compared sequences for the grey relational model, and also expressed with matrixes as follows:



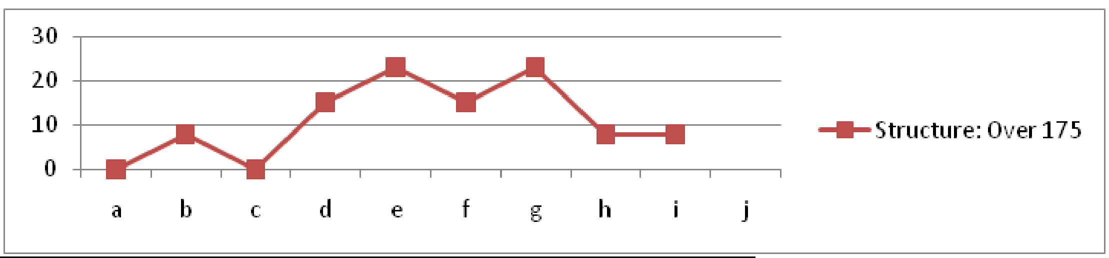
X-Axis	Subject Structure 160cm - 165 cm (S2)
Y-Axis %	Perceived Comfortable Body Points

Figure 4.5b. Subject Structure 160cm – 165cm (S2)



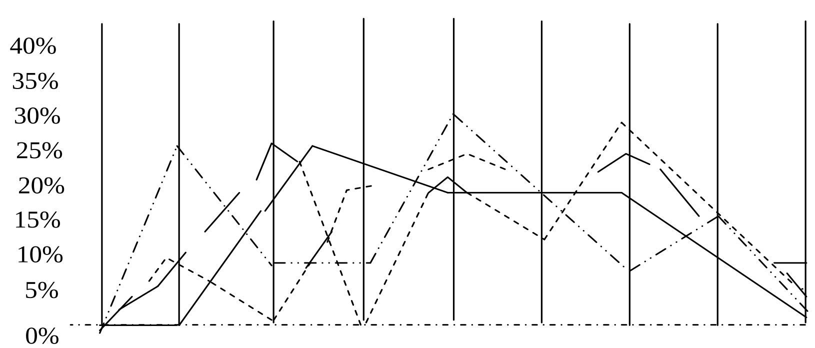
X-Axis	**Subject Structure 165cm - 175 cm (S3)**
Y-Axis %	Perceived Comfortable Body Points

Figure 4.5c. Subject Structure 165cm – 175cm (S3)



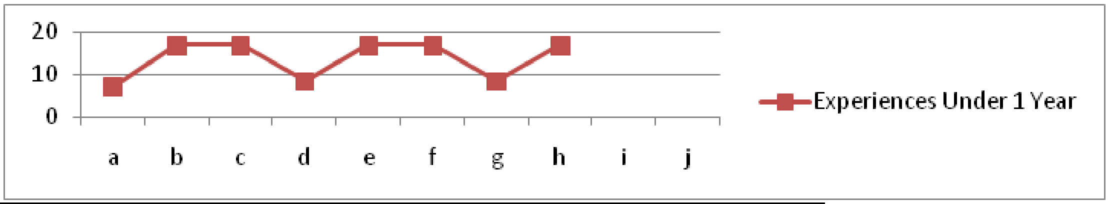
X-Axis	**Subject Structure Over 175 cm (S4)**
Y-Axis %	Perceived Comfortable Body Points

Figure 4.5d. Subject Structure Over 170 cm (S4)



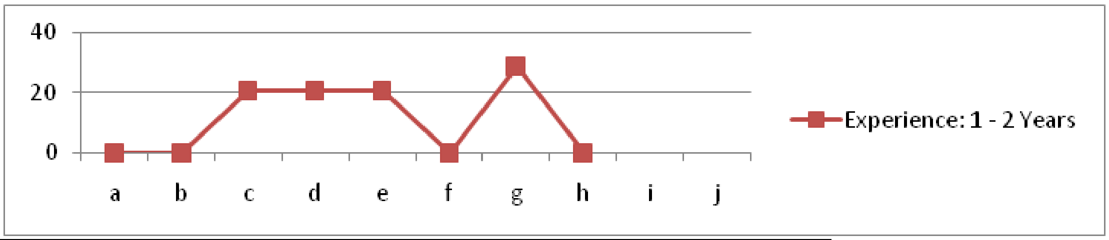
Statures ↓	Positions →	a	b	c	d	e	f	g	h	i
Under 160cm	(s_1)	0%	0%	17%	25%	17%	17%	17%	8.2%	0%
160cm – 165cm	(s_2)	0%	22%	7.1%	7.1%	28%	14%	7.1%	14%	0%
165 cm – 175cm	(s_3)	0%	7%	21%	0%	17%	14%	28%	10%	4%
Over 175cm	(s_4)	0%	8%	0%	15%	23%	15%	23%	8%	8%

Figure 4.6. Diagram of the Correlation between the subjects' Statures and the Perceived Comfortable Positions



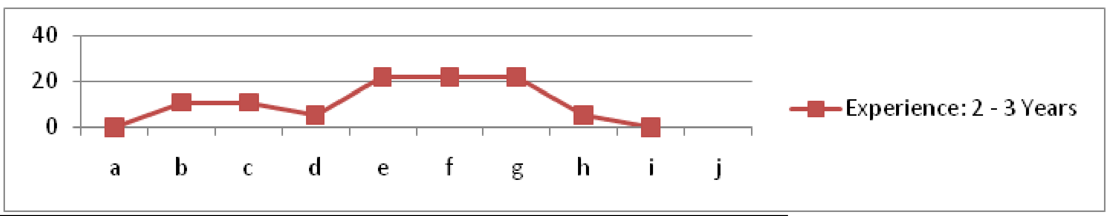
X-Axis	Subjects Experience: Under 1 year (e1)
Y-Axis %	Perceived Comfortable Body Points

Figure 4.7a. Subject Experience: Under 1 year (e1)



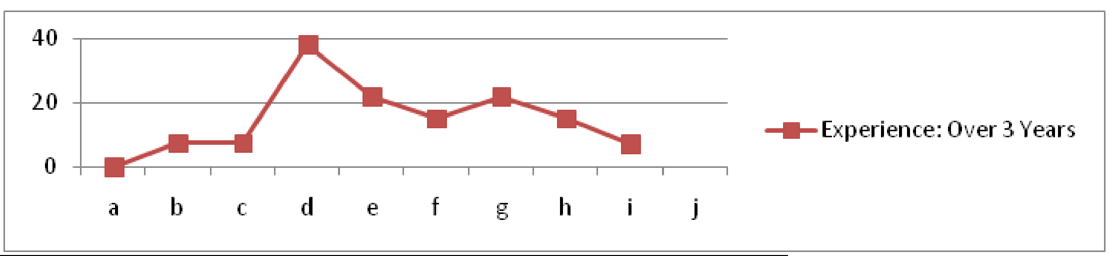
X-Axis	Subjects Experience: 1 - 2 year (e2)
Y-Axis %	Perceived Comfortable Body Points

Figure 4.7b. Subject Experience: 1- 2 year (e2)



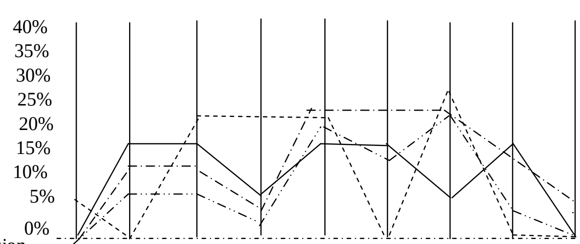
X-Axis	Subjects Experience: 2 - 3 year (e3)
Y-Axis %	Perceived Comfortable Body Points

Figure 4.7c. Subject Experience: 2 - 3 year (e3)



X-Axis	Subjects Experience: Over 3 year (e4)
Y-Axis %	Perceived Comfortable Body Points

Figure 4.7d. Subject Experience: Over 3 year (e4)



Experiences		Position: a	b	c	d	e	f	g	h	i
Under 1 year	(e_1)	7%	17%	17%	8.3%	17%	17%	8.3%	17%	0%
1 year – 2 years	(e_2)	0%	0%	21%	21%	21%	0%	29%	0%	0%
2 years – 3 years	(e_3)	0%	11%	11%	5.6%	22%	22%	22%	5.6%	0%
Over 3 years	(e_4)	0%	7.4%	7.4%	3.8%	22%	15%	22%	15%	7%

Figure 4.8. Diagram of the Correlation between the Subjects' Riding Experiences and the Perceived Comfortable Positions

(1) The correlation matrix of the subjects' statures and the perceived comfortable positions:

$$M_{\text{statures-Positions}} = \left[x_1(s_j)\right]_{jxn} = \begin{pmatrix} x_1(s_1) \\ x_2(s_2) \\ x_3(s_3) \\ x_4(s_4) \end{pmatrix}_{4x9}$$

$$= \begin{pmatrix} 0.000, 0.000, 0.167, 0.250, 0.167, 0.167, 0.167, & 0.082, 0.000 \\ 0.000, 0.215, 0.071, 0.071, 0.286, 0.143, 0.071, & 0.143, 0.000 \\ 0.000, 0.069, 0.207, 0.000, 0.172, 0.120, 0.276, & 0.103, 0.035 \\ 0.000, 0.076, 0.000, 0.154, 0.231, 0.160, 0.231, & 0.077, 0.077 \end{pmatrix} \quad (1)$$

Where:

X_1 (s_1) represents a compared sequence concerning the subjects' statures under 160 cm;
X_2 (s_2) represents a compared sequence concerning the subjects' statures between 160 cm and 165cm;
X_3 (s_3) represents a compared sequence concerning the subjects' statures between 165cm and 175cm;
X_4 (s_4) represents a compared sequence concerning the subjects' statures over 175 cm;

(2) The correlation matrix of the subjects' riding experiences and the perceived comfortable positions:

$$M_{\text{Experiences-Positions}} = \left[x_i(e_k)\right]_{jxn} = \begin{pmatrix} x_1(e_1) \\ x_2(e_2) \\ x_3(e_3) \\ x_4(e_4) \end{pmatrix}_{4x9}$$

$$= \begin{pmatrix} 0.000, 0.166, 0.167, 0.083, 0.167, 0.167, 0.083, & 0.167, 0.000 \\ 0.072, 0.000, 0.241, 0.214, 0.214, 0.000, 0.286, & 0.000, 0.000 \\ 0.000, 0.111, 0.111, 0.056, 0.222, 0.222, 0.222, & 0.056, 0.000 \\ 0.000, 0.074, 0.074, 0.038, 0.222, 0.148, 0.222, & 0.148, 0.074 \end{pmatrix} \quad (2)$$

Where:
X_1 (e_1) represents a compared sequence concerning the subjects' riding experiences under 1 year;
X_2 (e_2) represents a compared sequence concerning the subjects' riding experiences between 1 year and 2 years;
X_3 (e_3) represents a compared sequence concerning the subjects' riding experiences between 2 years and 3 years;
X_4 (e_4) represents a compared sequence concerning the subjects' riding experiences over 3 years;

Anthropometric Data analysis using Grey Relational Theory

To analyze the anthropometric characteristics of motorbike riders, the grey relational theory is used in this subsection. The following eight correlation matrixes were reconstructed to perform the grey relational analysis. Within each correlation matrix, the first row is operated as the reference sequence and so do the other rows as the compared sequences.

$$Mc_1\text{-}s_j = \begin{pmatrix} x_0(c_1) \\ x_1(s_1) \\ x_2(s_2) \\ x_3(s_3) \\ x_4(s_4) \end{pmatrix}_{5x9} = \begin{pmatrix} 0.000 & 0.110 & 0.140 & 0.130 & 0.160 & 0.150 & 0.100 & 0.080 & 0.130 \\ 0.000 & 0.000 & 0.167 & 0.250 & 0.167 & 0.167 & 0.167 & 0.082 & 0.000 \\ 0.000 & 0.215 & 0.071 & 0.071 & 0.286 & 0.143 & 0.071 & 0.143 & 0.000 \\ 0.000 & 0.069 & 0.207 & 0.000 & 0.172 & 0.138 & 0.276 & 0.103 & 0.035 \\ 0.000 & 0.076 & 0.000 & 0.154 & 0.231 & 0.154 & 0.231 & 0.077 & 0.077 \end{pmatrix} \quad (2.1)$$

$$Mc_3\text{-}s_j = \begin{pmatrix} x_0(c_3) \\ x_1(s_1) \\ x_2(s_2) \\ x_3(s_3) \\ x_4(s_4) \end{pmatrix}_{5x9} = \begin{pmatrix} 0.000 & 0.100 & 0.140 & 0.270 & 0.070 & 0.120 & 0.130 & 0.170 & 0.000 \\ 0.000 & 0.000 & 0.167 & 0.250 & 0.167 & 0.167 & 0.167 & 0.082 & 0.000 \\ 0.000 & 0.215 & 0.071 & 0.071 & 0.286 & 0.143 & 0.071 & 0.143 & 0.000 \\ 0.000 & 0.069 & 0.207 & 0.000 & 0.172 & 0.138 & 0.276 & 0.103 & 0.035 \\ 0.000 & 0.076 & 0.000 & 0.154 & 0.231 & 0.154 & 0.231 & 0.077 & 0.077 \end{pmatrix} \quad (2.3)$$

$$Mc_4\text{-}s_j = \begin{pmatrix} x_0(c_4) \\ x_1(s_1) \\ x_2(s_2) \\ x_3(s_3) \\ x_4(s_4) \end{pmatrix}_{5x9} = \begin{pmatrix} 0.000 & 0.160 & 0.170 & 0.100 & 0.150 & 0.160 & 0.130 & 0.130 & 0.000 \\ 0.000 & 0.000 & 0.167 & 0.250 & 0.167 & 0.167 & 0.167 & 0.082 & 0.000 \\ 0.000 & 0.215 & 0.071 & 0.071 & 0.286 & 0.143 & 0.071 & 0.143 & 0.000 \\ 0.000 & 0.069 & 0.207 & 0.000 & 0.172 & 0.138 & 0.276 & 0.103 & 0.035 \\ 0.000 & 0.076 & 0.000 & 0.154 & 0.231 & 0.154 & 0.231 & 0.077 & 0.077 \end{pmatrix} \quad (2.4)$$

$$M_{c_{1}\text{-}E_k} = \begin{pmatrix} x_0\ (c_1) \\ x_1\ (e_1) \\ x_2\ (e_2) \\ x_3\ (e_3) \\ x_4\ (e_4) \end{pmatrix}_{5x9} = \begin{pmatrix} 0.000 & 0.110 & 0.140 & 0.130 & 0.160 & 0.150 & 0.100 & 0.080 & 0.030 \\ 0.000 & 0.166 & 0.167 & 0.083 & 0.167 & 0.167 & 0.083 & 0.167 & 0.000 \\ 0.072 & 0.000 & 0.214 & 0.214 & 0.214 & 0.000 & 0.286 & 0.000 & 0.000 \\ 0.000 & 0.111 & 0.111 & 0.056 & 0.222 & 0.222 & 0.222 & 0.056 & 0.000 \\ 0.000 & 0.074 & 0.074 & 0.138 & 0.222 & 0.148 & 0.222 & 0.148 & 0.074 \end{pmatrix} \quad (3.1)$$

$$M_{c_{2}E_k} = \begin{pmatrix} x_0\ (c_2) \\ x_1\ (e_1) \\ x_2\ (e_2) \\ x_3\ (e_3) \\ x_4\ (e_4) \end{pmatrix}_{5x9} = \begin{pmatrix} 0.000 & 0.120 & 0.070 & 0.070 & 0.100 & 0.080 & 0.150 & 0.150 & 0.260 \\ 0.000 & 0.166 & 0.167 & 0.083 & 0.167 & 0.167 & 0.083 & 0.167 & 0.000 \\ 0.072 & 0.000 & 0.214 & 0.214 & 0.214 & 0.000 & 0.286 & 0.000 & 0.000 \\ 0.000 & 0.111 & 0.111 & 0.056 & 0.222 & 0.222 & 0.222 & 0.056 & 0.000 \\ 0.000 & 0.074 & 0.074 & 0.138 & 0.222 & 0.148 & 0.222 & 0.148 & 0.074 \end{pmatrix} \quad (3.2)$$

$$M_{c_{3}E_k} = \begin{pmatrix} x_0\ (c_3) \\ x_1\ (e_1) \\ x_2\ (e_2) \\ x_3\ (e_3) \\ x_4\ (e_4) \end{pmatrix}_{5x9} = \begin{pmatrix} 0.000 & 0.100 & 0.140 & 0.270 & 0.070 & 0.120 & 0.130 & 0.170 & 0.000 \\ 0.000 & 0.166 & 0.167 & 0.083 & 0.167 & 0.167 & 0.083 & 0.167 & 0.000 \\ 0.072 & 0.000 & 0.214 & 0.214 & 0.214 & 0.000 & 0.286 & 0.000 & 0.000 \\ 0.000 & 0.111 & 0.111 & 0.056 & 0.222 & 0.222 & 0.222 & 0.056 & 0.000 \\ 0.000 & 0.074 & 0.074 & 0.138 & 0.222 & 0.148 & 0.222 & 0.148 & 0.074 \end{pmatrix} \quad (3.3)$$

$$M_{c_{4}E_k} = \begin{pmatrix} x_0\ (c_3) \\ x_1\ (e_1) \\ x_2\ (e_2) \\ x_3\ (e_3) \\ x_4\ (e_4) \end{pmatrix}_{5x9} = \begin{pmatrix} 0.000 & 0.160 & 0.170 & 0.100 & 0.150 & 0.160 & 0.130 & 0.130 & 0.000 \\ 0.000 & 0.166 & 0.167 & 0.083 & 0.167 & 0.167 & 0.083 & 0.167 & 0.000 \\ 0.072 & 0.000 & 0.214 & 0.214 & 0.214 & 0.000 & 0.286 & 0.000 & 0.000 \\ 0.000 & 0.111 & 0.111 & 0.056 & 0.222 & 0.222 & 0.222 & 0.056 & 0.000 \\ 0.000 & 0.074 & 0.074 & 0.138 & 0.222 & 0.148 & 0.222 & 0.148 & 0.074 \end{pmatrix} \quad (3.4)$$

Let $\zeta = 0.5$, substituting the sequence data of Matrixes (2.1) to (2.4) and (3.1) to (3.4) into Formulas (2s) and (3s), the grey relational grades were obtained as follows:

(1) The grey relational grades between each main comfortable position (c_m, m = 1,2,3,4) and the subjects' statures ($s_1 - s_4$):

(a) The location of handlebar (c_1) and the subjects' statures (s_1–s_4):
$\gamma(c_1, s_1)=0.7051$; $\gamma(c_1, s_2)=0.6324$; $\gamma(c_1, s_3)=0.6690$;
$\gamma(c_1, s_4)=0.7107$;
The grey relational order is

$$\gamma(c_1, s_4) > \gamma(c_1, s_1) > \gamma(c_1, s_3) > \gamma(c_1, s_2). \quad (4.1)$$

(b) The location of seat (c_2) and the subjects' statures (s_1–s_4):
$\gamma(c_2, s_1)=0.6273$; $\gamma(c_2, s_2)=0.7280$; $\gamma(c_2, s_3)=0.6443$;
$\gamma(c_2, s_4)=0.6458$;
The grey relational order is

$$\gamma(c_2, s_2) > \gamma(c_2, s_4) > \gamma(c_2, s_3) > \gamma(c_2, s_1). \quad (4.2)$$

(c) The location of footrest-board (c_3) and the subjects' statures (s_1–s_4):
$\gamma(c_3, s_1)=0.7770$; $\gamma(c_3, s_2)=0.7082$; $\gamma(c_3, s_3)=0.6900$; $\gamma(c_3, s_4)=0.6593$;
The grey relational order is

$$\gamma(c_3, s_1) > \gamma(c_3, s_2) > \gamma(c_3, s_3) > \gamma(c_3, s_1). \quad (4.3)$$

(d) The space of footrest-board (c_4) and the subjects' statures (s_1–s_4):
$\gamma(c_4, s_1)=0.7520$; $\gamma(c_4, s_2)=0.7211$; $\gamma(c_4, s_3)=0.6737$; $\gamma(c_4, s_4)=0.6102$;
The grey relational order is

$$\gamma(c_4, s_1) > \gamma(c_4, s_2) > \gamma(c_4, s_3) > \gamma(c_4, s_1). \quad (4.4)$$

(2) The grey relational grades between each main comfortable position (c_m, m = 1,2,3,4) and the subjects' statures ($e_1 - e_4$):

(a) The location of footrest-board (c_1) and the subjects' riding experiences (e_1–e_4):

$\gamma(c_1, e_1)$=0.7353; $\gamma(c_1, e_2)$=0.4897; $\gamma(c_1, e_3)$=0.6796; $\gamma(c_1, e_4)$=0.6691
The grey relational order is
$\gamma(c_1, e_1) > \gamma(c_1, e_3) > \gamma(c_1, e_4) > \gamma(c_1, e_2)$. (5.1)

(b) The location of seat (c_2) and the subjects' riding experiences (e_1–e_4):
$\gamma(c_2, e_1)$=0.7063; $\gamma(c_2, e_2)$=0.5056; $\gamma(c_2, e_3)$=0.6833; $\gamma(c_2, e_4)$=0.7471
The grey relational order is
$\gamma(c_2, e_4) > \gamma(c_2, e_1) > \gamma(c_2, e_3) > \gamma(c_2, e_2)$. (5.2)

(c) The location of footrest-board (c_3) and the subjects' riding experiences (e_1–e_4):
$\gamma(c_3, e_1)$=0.7527; $\gamma(c_3, e_2)$=0.5787; $\gamma(c_3, e_3)$=0.6769; $\gamma(c_3, e_4)$=0.6705
The grey relational order is
$\gamma(c_3, e_1) > \gamma(c_3, e_3) > \gamma(c_3, e_4) > \gamma(c_3, e_2)$. (5.3)

(d) The space of footrest-board (c_4) and the subjects' riding experiences (e_1–e_4):
$\gamma(c_4, e_1)$=0.8641; $\gamma(c_4, e_2)$=0.5029; $\gamma(c_4, e_3)$=0.6572; $\gamma(c_4, e_4)$=0.6330
The grey relational order is
$\gamma(c_4, e_1) > \gamma(c_4, e_3) > \gamma(c_4, e_4) > \gamma(c_4, e_2)$. (5.4)

The Suggested Characteristic Angles of Riding Postures for Motor bike Riders

To further analyze the relationship between the perceived comfortable positions and the obtained characteristic angles in terms of the ranges of subject's statures, a relative table was constructed as shown in Table 4.16.

The characteristic angles are relevant to the joints defined as the characteristic points or the perceived comfortable positions of riding postures in this study. They are also one of the important anthropometric variables concerning the riding comfort. As the percentage of each perceived comfortable position, P_j%, indicates the degree of comfort at the corresponding characteristics point, it can be used as a weighted parameter to derive an average characteristic angle accepted by the overall subjects. The formula can be expressed as below:

$$\theta i = \frac{\sum_{j=i}^{4} \theta_{ij} w_{ij}}{\sum_{j=i}^{4} w_{ij}}, \qquad (6)$$

$$w_{ij} = 1 - P_j\%,\ i = 1,2,3,\ldots,6,\ j = 1,2,3,4$$

Where

θ_i represents a weighted average characteristic angle accepted by the overall subjects;
θ_{ij} is an obtained characteristic angle of the corresponding range of subjects' statures;
w_{ij} is a weighted parameter of the corresponding range of subject's statures representing the complement of the percentage of having a comfortable feeling corresponding to each characteristic point (P_j).

Substituting the related data of Table 6 into Formula (6), the weighted average characteristic angles were obtained as follows:

$$\overline{\theta_1} = \frac{(158.1x1) + (159.5x0.785) + (162.3x0.931) + (158.3x0.924)}{1+0.785+0.931+0.924} = 159.5$$

$$\overline{\theta_2} = \frac{(42.6x0.833) + (40.9x0.929) + (39.1x0.793) + (37.6x1)}{0.833+0.929+0.793+1} = 40.0$$

$$\overline{\theta_3} = \frac{(131.8 \text{x} 0.75) + (135.3 \text{x} 0.929) + (143.5 \text{x} 1) + (145.2 \text{x} 0.846)}{0.75 + 0.929 + 1 + 0.846} = 139.3$$

$$\overline{\theta_4} = \frac{(171.7 \text{x} 0.833) + (171.3 \text{x} 0.857) + (171.6 \text{x} 0.862) + (165.3 \text{x} 0.846)}{0.833 + 0.857 + 0.862 + 0.848} = 169.9$$

$$\overline{\theta_5} = \frac{(107.1 \text{x} 0.833) + (103.9 \text{x} 0.929) + (104.8 \text{x} 0.724) + (99.3 \text{x} 0.769)}{0.833 + 0.929 + 0.724 + 0.769} = 103.8$$

$$\overline{\theta_6} = \frac{(82.8 \text{x} 0.918) + (79.7 \text{x} 0.857) + (78.6 \text{x} 0.897) + (74.9 \text{x} 0.923)}{0.918 + 0.857 + 0.897 + 0.923} = 79.0$$

As the motorbike is regarded as a constrained workstation, the problem for riders of different sizes to fit the same workstation is of vital importance. Besides, the anthropometric data used for designing a motorbike should be reasonably representative of the population of motorbike riders. To derive a set of suggested characteristic angles accepted by all the stature ranges of motorbike riders in Nigeria, we defined the tolerance as an average difference of the characteristic angle between its maximum and minimum of the measurement. The suggested characteristic angles of riding postures can be derived by using the following formula:

$$\theta i = \overline{\theta i} \pm \Delta\theta i; \ \Delta\theta i = \frac{|\overline{\theta i} - (\theta i)_{\max}| + |\overline{\theta i} - (\theta i)_{\min}|}{2} \qquad (7)$$

Where

$\Delta\theta_i$ is the tolerance of the characteristic angle;

$(\theta_i)_{max}$ is the maximum within the ordered sequence of the characteristic angle;

$(\theta_i)_{min}$ is the minimum within the ordered sequence of the characteristic angle.

Using Formula (7), the ordered sequence, tolerance and the suggested characteristic angles were determined as follows:

$\theta_1 = (158.1, 158.3, 159.5, 159.5, \overline{162.3}), \Delta\theta_1 = 2.1$

$\theta_1 = 159.5 \pm 2.1$ (8.1)

$\theta_2 = (37.6, 39.1, 40.0, 40.9, \overline{42.6}), \Delta\theta_2 = 2.5$

$\theta_2 = 40.0 \pm 2.5$ (8.2)

$\theta_3 = (131.8, 135.3, 139.3, 143.5, \overline{145.2}), \Delta\theta_3 = 6.7$

$\theta_3 = 139.3 \pm 6.7$ (8.3)

$\theta_4 = (165.3, 169.9, 171.3, 171.6, 171.7), \Delta\theta_4 = 3.2$

$\theta_4 = 169.9 \pm 3.2$ (8.4)

$\theta_5 = (99.3, 130.8, 103.9, \overline{104.8}, 107.1), \Delta 5 = 3.9$

$\theta_5 = 103.8 \pm 3.9$ (8.5)

$\theta_6 = (74.9, 78.6, 79.0, 79.7, \overline{82.8}), \Delta\theta_6 = 4.0$

$\theta_6 = 79.0 \pm 4.0$ (8.6)

Based on the resultant data of Equations (8.1) to (8.6), a set of suggested characteristic angles of riding postures for motorbike riders in Nigeria was derived as shown in Table 7.

Body comfort is generally associated with biochemical factors. Since the human musculoskeletal system is not a perfectly rigid mechanical linkage articulated by idealized spherical or axial joints, it is difficult to measure the segment lengths and joint angles of the human body directly by a conventional anthropometric approach. In this experiment, an articulated linkage representation of the human skeletal system was constructed with nine characteristic points and six characteristic angles. These characteristic points considered as the perceived comfortable positions of riding postures were measured through the 2D anthropometer, and then the characteristic angles were obtained by the algebraic calculations of geometry.

Table 6. A Relative Table between the Perceived Comfortable Positions and the obtained Characteristic Angles in terms of the Ranges of Subject's Statures.

	Neck		Shoulder		Elbow		Lower back		Hip		Knee	
	θ_1	b	θ_2	C	θ_3	d	θ_4	f	θ_5	g	θ_6	H
Under 160cm	158.1	0%	42.6	17%	131.8	25%	171.7	17%	107.1	17%	82.7	8.2%
160-165cm	159.5	22%	40.9	7.1%	135.3	7.1%	171.3	14%	103.9	7.1%	79.7	14%
165-175cm	162.3	7%	39.1	21%	143.5	0%	171.6	14%	104.8	28%	78.6	10%
Over 175cm	158.3	8%	37.6	0%	145.2	15%	165.3	15%	99.3	23%	74.9	8%

Table 7. List of the Suggested Characteristic Angles of Riding Postures for Motorbike Riders in Nigeria

Involved joint	**Neck**	**Shoulder**	**Elbow**
Characteristic angle	θ_1	θ_2	θ_3
Range of the angle	$157.4^0 < \theta_1 < 161.6^0$	$37.5^0 < \theta_2 < 42.5^0$	$132.6^0 < \theta_3 < 146.0^0$
Involved joint	Lower back	Hip	Knee
Characteristic angle	θ_4	θ_5	θ_6
Range of the angle	$166.7^0 < \theta_4 < 173.1^0$	$99.9^0 < \theta_5 < 107.7^0$	$75.0^0 < \theta_6 < 83.0^0$

Analysis of Proposed Characteristics Angles of a Motor bike Workstation

A motor bike can be considered a constrained workstation in which there is very limited available adjustment to suit different needs of riders. To develop satisfactory motor bike, anthropometric data should be used to improve and specify the physical dimensions of workstations as well as applied to the motor bike design using average characteristics angles to get the proposed characteristics angles.

The height of the human linkage representation is about 165 cm hypothetically, and the characteristic angles are: θ1 = 160°, θ2 = 41°, θ3 = 144°, θ4 = 171°, θ5 = 102° and θ6 = 81° respectively with the highlighted points/angles **(Point e, Point g, and Point i)** as very important as they are the contact points between the rider and the workstation. They can be used to determine the location of handlebar, the location of seat, the location of footrest-board, and the space of footrest-board. **Table 8**

Table 8. Characteristic Angles of Proposed Motor Bike

Characteristic Angles	**Proposed Motor bike (x^0)**
θ_1	160^0
Point e. θ_2	41^0
θ_3	144^0
Point g. θ_4	171^0
θ_5	102^0
Point i. θ_6	81^0

CONCLUSION

This study identifies the problem of MSD among motorbike riders in Nigeria. The results of this study show that the agreement between a questionnaire on musculoskeletal disorders for the low back and other parts of the body and a physical examination is fair to good. It is the physical examination definition that included pain manifestations that offered the best agreement with the questionnaire. A shorter time interval between the administrations of the two tests also yields a better agreement. Investigators should consider these results before choosing a method to measure the presence of musculoskeletal disorders of the low back pain, neck and all other regions.

The ranges of suggested characteristic angles concerning riding postures are acceptable for motorbike riders in Nigeria and can be used as reference data for motorbike design for Nigerians. This proposed anthropometric measurement may result practically to pinpoint the joints of lower back and hip. However, it is still recommendable as it provides researcher a convenient and inexpensive anthropometric measurement. The survey shows that 79% of the bike riders have lower back pain; the anthropometric date showed that the existing motor bikes and the riders do not match which require the generation of an anthropometric data for the riders and their motor bikes (workstation). The height of the human linkage representation is about 165 cm hypothetically, and the characteristic angles are: θ1(head/Neck) = 160°, θ2(Elbow/Chest) = 41°, θ3(Elbow) = 144°, θ4(Waist/buttocks) = 171°, θ5(Waist/Laps) = 102° and θ6(Laps/Ankle = 81° respectively.

In the course of this research work, it was observed from literature that there are other factors responsible for the causes of MSD such as prolonged sitting, smoking, vibration (both deterministic and stochastic), manual intensive work, mechanical pressure concentration etc, the impacts of these factors on the riders tend to reduce when the right anthropometric data is consulted for the design of the motor bikes. This investigation led to the generation of anthropometric data for the population under consideration for a better design of the anticipated motor bikes.

Anthropometry for Design for Nigerians

At present, there are no population data on the anthropometric of motor bike riders in Nigeria. One of the objectives of the study is to collect data on reasonable number of body dimensions, which can be useful for the design of motor bikes for motor bike riders. It is expected that this study will provide help to designers, who have been unable to design specifically suited products (motor bikes) for motor bike rider's population for lack for proper data.

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