ORIGINAL ARTICLE

VEHICLE OCCUPANT ACCOMMODATION BASED ON REPRESENTATIVE ANTHROPOMETRY

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ABSTRACT

Digital human modelling (DHM) offers a way of representing the intended vehicle users and task requirements using their anthropometric dimensions and computer graphics. This helps in avoiding the need for early user trials leading to a massive time saving. Also, this enables the early consideration of human factors issues in the vehicle design process thereby decreasing the possibility of costly and impractical adjustments at the advanced vehicle development phases. An ergonomic automotive seat suitable for the Nigerian population was designed using CATIA V5 software based on proposed seat dimensions from our previous study. This work seeks to evaluate the suitability of the proposed seat and SAE J1100 vehicle package dimensions for the Nigerian population based on their anthropometry. Six custom built Nigerian manikins were postured as drivers and passengers in a vehicle package based on CATIA V5 Human Builder vehicle occupant accommodation and another seven manikins were positioned on the seat designed for the Nigerian population. Rapid Upper Limb Assessment (RULA) ergonomic analysis conducted on all the manikins in the vehicle package both as drivers and passengers' showed that the SAE J1100 package dimensions are unsuitable for the Nigerian population with overall RULA scores between 3 to 6 for drivers and 4 to 5 for passengers. The choice of transmission type and an enhanced seat height were found to provide improved body and postural comfort for the Nigerian driver population with a difference of 1 to 3 in the final RULA scores. However, an improved seat height was found not to give enhanced body and postural comfort for most of the Nigerian passenger population due to the effects of other SAE J1100 package dimensions with uniform overall RULA scores of 4 and 5. Finally, the seat designed for the Nigerian population proved to fit and accommodate them comfortably with acceptable RULA scores of 2 for all the seven Nigerian manikins analyzed.

Keywords: *Digital Human Modelling, Rapid Upper Limb Assessment, Vehicle Occupant Accommodation, Ergonomics*

INTRODUCTION

The need to use DHM in product design particularly automotive design is very important to ensure proper vehicle accommodation. Digital human modelling helps in evaluating fit with respect to body shape and size due to the variability in the target population of users. Three manikins of 5th percentile female and 95th percentile male were modelled and fitted in a virtual vehicle environment using eleven body dimensions. The manikins were modelled based on data available for the US population. Issues regarding international populations due to differences in anthropometry were highlighted (Boyd et al., 2014).

Marshall et al. conducted a study that used DHM systems to design vehicle interiors for international populations. This is because vehicle occupant accommodation designs are based on the SAE standards which are applied worldwide but the data used to develop those standards are based on the US population with some dimensions estimated in the 1960s. This leads to poor accommodation of international populations. However, the use of DHM ensures both univariate and multivariate accommodation issues are satisfied. The study used Adult Data software where 56 subjects from the UK population were used to determine user accommodation and changes were recommended to an auto manufacturer (Marshall et al., 2010).

In a study to create a standard passenger posture in airplane seats using DHM, Green & Hudson proposed a method to accurately position representative subjects from the passenger population having extreme anthropometry on digital mock-ups of aircraft seats (Green & Hudson, 2010).

Hogberg & Case proposed the use of virtual manikins in a design for all approach in the automotive development process thereby enlarging the vehicle manufacturer's market reach and enhancing the vehicles to accommodate larger populations (Hogberg & Case, 2002). Furthermore, an objective and subjective survey in addition to ergonomics analysis using DHM was conducted in a study to compare the comfort ratings of imported vehicles against locally made vehicles in Malaysia however, American anthropometric data was used to create the manikins (Mohamed, 2010; Mohamed & Yusuff, 2007). Equally, the suitability of German cars on Japanese males was evaluated using RAMSIS

DHM and found to fit them (Mačužić & Lukić, 2017).
Shi & Paul proposed a framework of determinants of driver versus second row occupant posture modelling. The difference between driver and passenger posture was highlighted and input parameters for driver and second row occupant digital human modelling were proposed. A method by which driver posture can be modified to predict second row occupant posture was also proposed. This study was mainly a literature review and theoretical modelling (Shi & Paul, 2011).

METHODS

Digital Human Modelling

In order to accommodate the intended population in a vehicle design, three anthropometric techniques are commonly used: a population model, a manikins-based method and a composite method that integrate the previous two methods. The manikins-based method utilizes current body proportions data representing the target users to specify a group of boundary manikins having anthropometric extremes to depict a specified category of users. The anthropometric boundary figures of 5^{th} percentile female and 95^{th} percentile male are generally utilized in the design of vehicle seats and occupant packaging standards. These manikins are then positioned in computer 3D environment of the designed vehicle (Gkikas, 2012; Parkinson & Reed, 2006; Reed & Flannagan, 2000; Shi & Paul, 2011).
The anthropometry of the intended user population, seat design dimensions, task definitions and the layout of the interior package are the elements used for modelling vehicle occupant posture. Several studies have identified stature, weight, gender and sitting height as the vital elements related to the intended population anthropometry which are critical for determining vehicle sitting posture (Archer & Kolich, 2005; Lee et al., 2008; Reed & Flannagan, 2000; Reed, Manary, Flannagan, et al., 1999; Reed et al., 2000b, 2000a, 2002; Reed, Manary, & Schneider, 1999; Reed, Roe, et al., 1999; Shi & Paul, 2011).
The seat height variable (H30) has been established as having the greatest influence on both occupant and driver posture (Shi & Paul, 2011). Also, the type of transmission has been determined as having a significant effect on driver posture (Porter & Porter, 2001; Shi & Paul, 2011). Based on the foregoing, the digital human modelling of the Nigerian population for vehicle occupant accommodation and seat design was conducted as presented in the following sections.

Creating a Population File

The CATIA V5 Human Builder provides the possibility of creating manikins from seven default countries namely: America, Canada, Germany, France, Korea, Japan and China (Taiwan). In order to create manikins that truly represent the Nigerian population, a population file was created based on the Nigerian anthropometric data obtained from sample subjects of the Nigerian population (Uba et al., 2018) and subsequently added into CATIA V5. The population file represents a population (Nigeria in this case), it comprises the anthropometric dimensions of the Nigerian population. It adheres to a very specific pattern. It is arranged in units of data; every unit should start and finish with a keyword. The finishing keyword of one unit is the starting keyword of the following unit. The finishing keyword for the final unit is END. It has two sections as follows:

- MEAN_STDEV M
- MEAN_STDEV F

There are 103 anthropometric variables needed to create the population file. However, out of the 60 body dimensions obtained, only 44 variables could be used to create the population file and the other 59 variables were determined by CATIA automatically based on regression equations (Dassault Systèmes, 2005). The means and standard deviations of the 44 variables were specified as follows:
<variable> <mean> <stddev>
Where <variable> is the reference number of the variable, <mean> is the variable's mean value and <stddev> is the variable's standard deviation.
All the length values must be given in centimetres while the weight value is given in kilogrammes. The keywords are case sensitive; hence, the upper-case letters were used throughout the population file. After the population file has been created, it was loaded into CATIA V5 (Figure 1).

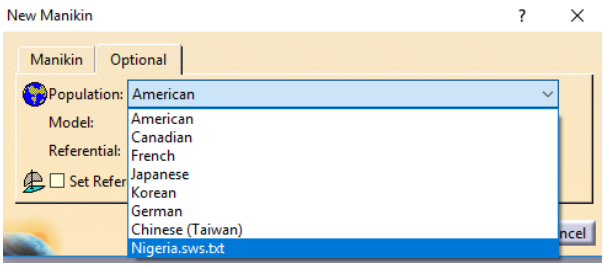

Figure 1: Loaded Nigerian Population Anthropometry

Driver Modelling

Based on the three key anthropometric variables of stature, sitting height and weight identified as having the greatest influence on driver posture, custom built manikins were created in CATIA V5 Human Builder from the Nigerian population anthropometry added in the previous section. Two manikins of actual individuals from the Nigerian sample population lying in the limits of the anthropometric variables based on their raw anthropometric data were created by manually inputting (Figure 2) the values for the 44 anthropometric dimensions while CATIA V5 determines the values for the remaining 59 dimensions automatically (Figure 3). This was done for each of the three key anthropometric variables for both male and female genders as shown in the Table 1:

Table 1: Anthropometric Variables/Percentiles for Driver/Passenger Modelling

No	Anthropometric Variable	Male	Female
1	Stature	95th%	5th%
2	Weight	95th%	5th%
3	Sitting Height	95th%	5th%

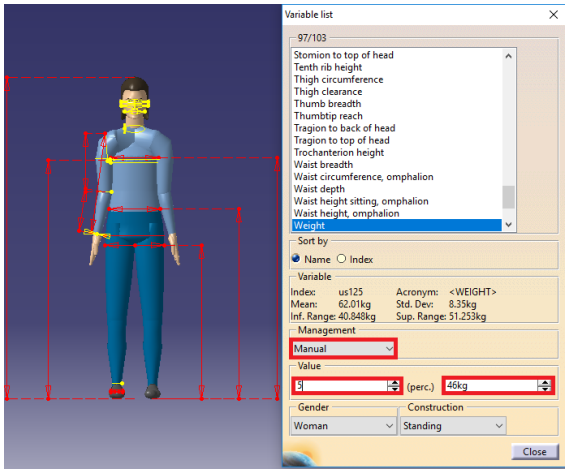

Figure 2: Manually Inputting Anthropometric Dimensions

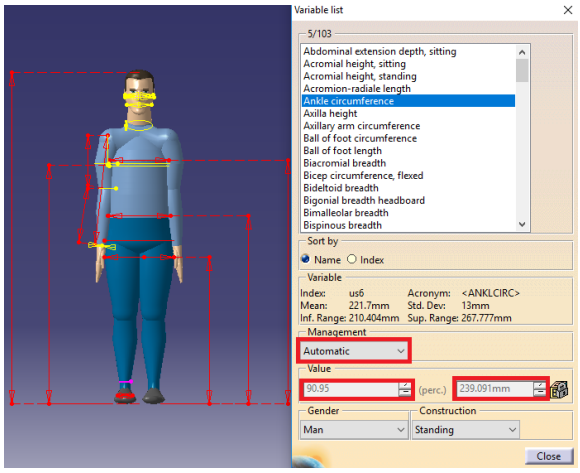

Figure 3: Automatic Determination of Anthropometric Dimensions

Package Definition

A package was created from the vehicle occupant accommodation toolbar in CATIA V5 Human Builder (Figure 4). The package is a set of vehicle proportions used by the occupant posture prediction as an input for predicting the posture of the vehicle occupant based on the anthropometry of the occupant, package dimensions and task definitions. The package dimensions used by CATIA V5 Human Builder for this research work is based on the Society of Automotive Engineers (SAE) J1100 Standard of September 2005. All the manikins were placed in the package using the default dimensions for the seat, steering wheel, accelerator pedal and footrest sections. Additionally, the manikins were also placed in the package based on all the default dimensions except for seat height (H30) which was identified as the package parameter having the most effect on driver posture. In this instance, the seat height was changed from the default value to the one proposed for the Nigerian population (Muhammad et al., 2018). Finally, RULA ergonomics analysis was performed on all the 6 driver manikins to assess whether the SAE package dimensions are suitable for the Nigerian driver population as well as the effect of the change of seat height (H30) on several drivers with different anthropometry. The impact of transmission type on driver comfort was also ascertained.

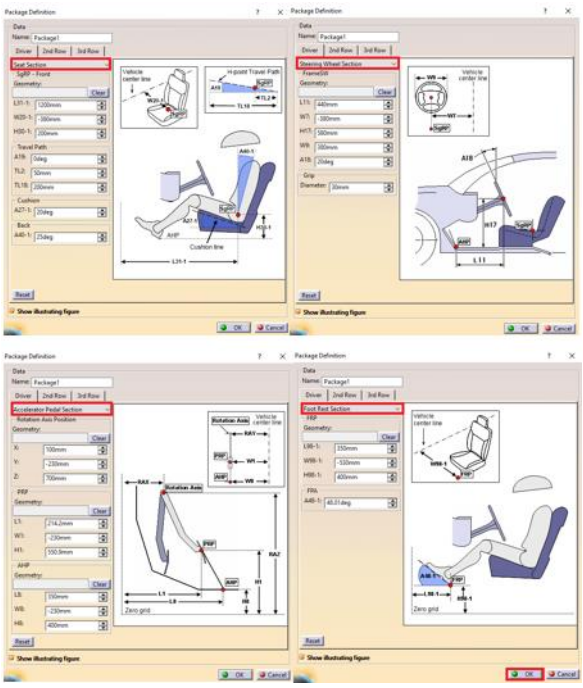

Figure 4: Driver Package Definition

Occupant Posture Prediction

All the generated manikins for the driver were postured in the created driver package separately. There are three methods for predicting the driver posture (cascade, cascade2 and optimization). The cascade2 method was used for this research work for predicting driver postures as it is the only one of the three methods that allows the selection of the transmission type for the driver which has been identified as having significant effect on driver posture. The driver seating position was selected and both the automatic and manual transmission types were selected alternatively for each manikin in order to ascertain the effect of transmission types on various drivers with different anthropometry (Figure 5). Finally, all the manikins were positioned as drivers in the vehicle package according to the posture prediction method selected based on the package dimensions and individual manikin anthropometry.

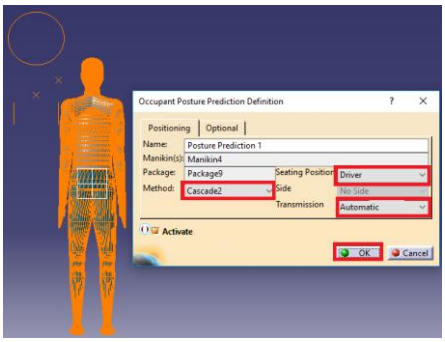

Figure 5: Selecting Posture Prediction Method, Driver Seating Position & Transmission Type

Passenger Modelling

The passenger modelling is the same as that of driver modelling above.

Package Definition

The passenger package definition is similar to that of the driver above. All the default values for the second and third row passenger sections were accepted. Here also, the seat height (H30) was changed from the default value to the proposed value for the Nigerian population (Figure 6).

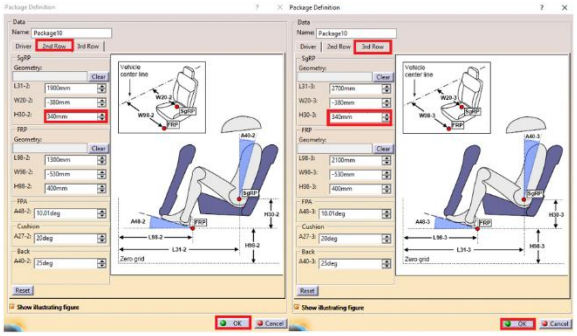

Figure 6: Second & Third Row Passenger Package and Seat Height Definition

Occupant Posture Prediction

All the generated manikins for the passengers were positioned in the created passenger package. All the manikins were postured separately by selecting the individual manikins as well as the corresponding package. The optimization posture prediction method was used for this research work for predicting passenger postures as it is the only one of the three methods that allows the prediction of passenger postures. The front, second and third row passenger seating positions were selected and both the right, centre and left sides were selected alternatively for each manikin in the second and third rows so as to determine the effect of sitting sides on various passengers with different anthropometry (Figure 7). The manikins were positioned as passengers in the package according to the posture prediction method selected based on the package dimensions and individual manikin anthropometry. Finally, RULA ergonomics analysis was performed on all the 6 passenger manikins to assess whether the SAE package dimensions are suitable for the Nigerian passenger population as well as the effect of the change of seat height (H30) on several passengers with different anthropometry.

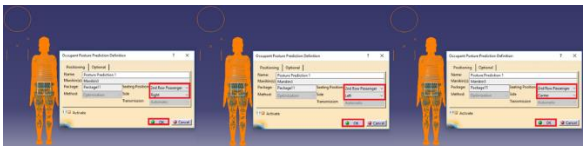

Figure 7: Selecting Passenger Seating Position

Seat Design

The seat was designed in the CATIA V5 Part Design workbench by means of a geometrical set. The headrest, seatback, seat cushion, right and left armrests and the seat base were designed to form the complete seat.

Seat Digital Modelling

Based on the six anthropometric variables of buttock popliteal length, seated popliteal height, Interscye distance, shoulder Bideltoid breadth, hip width and shoulder height sitting out of the eleven variables used in establishing the seat dimensions for the Nigerian population (Table 2), custom built manikins were created as described in the driver modelling section. The created manikins were then manually positioned on the designed seat using the standard pose and posture editor tools of the Human Builder workbench as well as the manipulation tool of the assembly design workbench. Finally, RULA ergonomics analysis was performed on the positioned manikins on the designed seat to assess the comfort level of the seat on the Nigerian population with different anthropometry.

RULA Ergonomics Analysis

The RULA ergonomics analysis was conducted on all the 6 manikins for the driver, 6 manikins for the passengers and 7 manikins for the seat design. After all the manikins have been positioned in the driver and passenger package as well as the designed seat, the right side of the manikin was chosen as the side to be analysed. The intermittent posture was selected for all the manikins as it best suits the human posture in a vehicle environment. All the other parameters were left at the default settings (Figure 8). The score for both the final and individual body parts analysis is a combination of numbers from 1 to 7 and colours green to red. Numbers 1 and 2 are indicated by the green colour which signifies acceptable comfort and posture levels. Numbers 3 and 4 are indicated by the yellow colour which shows the need to investigate further and changes might be required. Numbers 5 and 6 are indicated by the orange colour which denotes that further investigation and changes are required soon. Finally, number 7 is indicated by the colour red which implies that further investigation and changes are required immediately.

Table 2: Anthropometric Variables and Percentiles for Seat Human Modelling

No	Anthropometric Variable	Gender & Percentile
1	Hip Width	95th% Female
2	Buttock Popliteal Length	5th% Female
3	Popliteal Height Sitting	5th% Female
4	Shoulder Height Sitting	5th% Female, 95th% Male
5	Interscye Distance	95th% Male
6	Shoulder Bideltoid Breadth	95th% Male

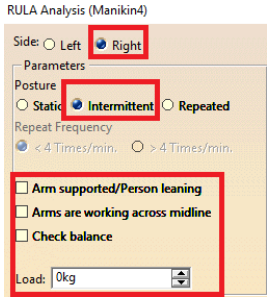

Figure 8: Setting the RULA Analysis Parameters

RESULTS

Driver Accommodation and RULA Analysis

Stature

Figure 9 shows a Nigerian female manikin 5th percentile in stature positioned as a driver in the vehicle package based on the default SAE package dimensions. The top figure represents the selection of manual transmission type for the driver while the bottom figure represents automatic transmission selection. As can be seen from the RULA analysis results, the overall score for the automatic transmission is 4 which indicates the need to adjust the package dimensions in order to make it more comfortable for the short Nigerian female

driver. The overall score of 6 for the manual transmission shows that the small Nigerian female driver would be very uncomfortable in the vehicle based on the bad fit between the package dimensions and her anthropometry.

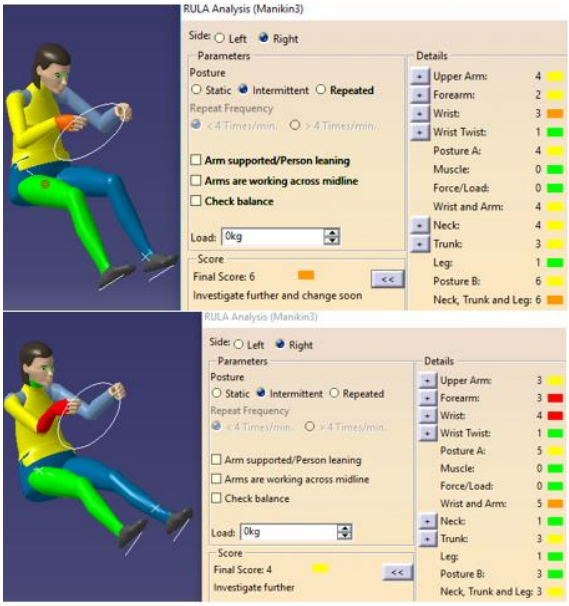

Figure 9: Nigerian Female Manikin 5th percentile in Stature Postured as a Driver in the Vehicle Package Based on SAE J1100 Package Dimensions with Manual and Automatic Transmission Selection (top and bottom images respectively)

The detailed analysis results for the automatic transmission reveals some serious pains for the driver in her upper arm, forearm, wrist and trunk with the overall posture of the arm very undesirable. The manual transmission is even more uncomfortable for the driver with pains in the neck, trunk, wrist, forearm and upper arm. The overall postures of the arm, neck, trunk and leg are uncomfortable. The automatic transmission gives improved comfort than manual transmission to the small Nigerian female driver in the upper arm, neck and the overall posture of the leg, trunk and neck. The manual transmission on the other hand gives the short Nigerian female driver better comfort than automatic transmission in the forearm, wrist and overall arm posture.

Figure 10 shows the same female manikin positioned in the vehicle package as above. However, the seat height (H30) value was changed from the default SAE value of 200mm to the value of 340mm recommended for the Nigerian population. As can be seen from the figure, there is an improvement in the overall RULA analysis score for the automatic transmission from 4 to 3. On the other hand, the total RULA score for the manual transmission type remains the same (6) as that of the default SAE dimensions.

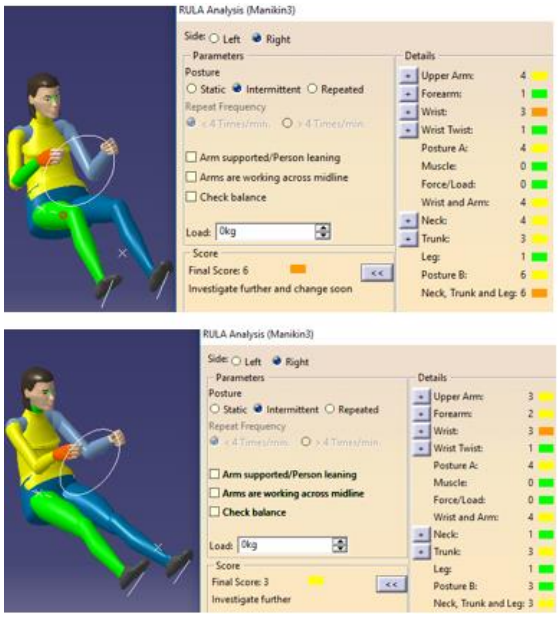

Figure 10: Nigerian Female Manikin 5th percentile in Stature Postured as a Driver in the Vehicle Package using 340mm as the Seat Height (H30) Value with Automatic and Manual Transmission Selection (bottom and top images respectively)

The comparison between the default SAE seat height and that recommended for the Nigerian population on the Nigerian female driver 5th percentile in stature for the automatic transmission type shows an improvement in forearm comfort from 3 to 2, wrist from 4 to 3 and overall arm posture from 5 to 4. The comfort levels for the upper arm, wrist twist, neck, trunk, leg and the overall posture of the trunk, neck and leg remains the same for both. As for the manual transmission, there is an improvement in the comfort level of the forearm from 2 to 1 which is as a result of an improved seat height.

Figure 11 presents a Nigerian male manikin 95th percentile in stature postured as a driver in the vehicle package based on the default SAE package proportions. The RULA analysis results indicate a final score of 5 for the automatic transmission which shows the need to modify the package proportions in order to make it more comfortable for the tall Nigerian male driver. The total score of 6 for the manual transmission indicates that the tall Nigerian male driver would be very uncomfortable in the vehicle based on the

mismatch between the package proportions and his anthropometry.

The detailed analysis results for the automatic transmission reveals some severe pains for the driver in his forearm, wrist, neck and trunk with the overall posture of the leg, neck and trunk very intolerable. The manual transmission is also uncomfortable for the driver with pains in the neck, trunk, wrist, forearm and upper arm. The overall postures of the arm, neck, trunk and leg are unacceptable. The automatic transmission gives improved comfort than manual transmission to the tall Nigerian male driver in the upper arm and the overall posture of the arm.

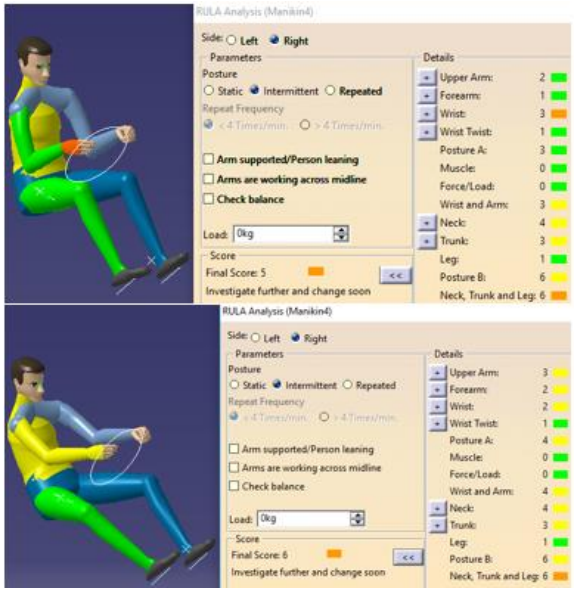

Figure 11 Nigerian Male Manikin 95th percentile in Stature Postured as a Driver in the Vehicle Package Based on SAE J1100 Package Dimensions with Automatic and Manual Transmission Selection (top and bottom images respectively)

Figure 12 shows the same male manikin postured in the vehicle package as above. However, the seat height (H30) value was changed from the default SAE value to the value of recommended for the Nigerian population. As can be seen from the figure, there is no improvement in the overall RULA analysis score for both the automatic and manual transmission types. They both remain the same (5 and 6 respectively) as that of the default SAE dimensions.

The contrast between the default SAE seat height and that proposed for the Nigerian population on the Nigerian male driver 95th percentile in height for the automatic transmission type indicates an improvement in upper arm comfort from 2 to 1, forearm from 2 to 1, wrist from 3 to 2 and overall arm posture from 3 to 2. The comfort levels for the wrist twist, neck, trunk, leg and the overall posture of the trunk, neck and leg remains the same for both. As for the manual transmission, there is an improvement in the comfort level of the wrist from 3 to 2 due to an enhanced seat height.

Figure 12: Nigerian Male Manikin 95th percentile in Stature Postured as a Driver in the Vehicle Package using 340mm as the Seat Height (H30) Value with Automatic and Manual Transmission Selection (top and bottom images respectively)

Weight

Figure 13 shows a Nigerian female manikin 5th percentile in weight positioned as a driver in the vehicle package based on the default SAE package dimensions. From the RULA analysis results, the overall score for both the automatic and manual transmission types is 4 which indicates the need to adjust the package dimensions in order to make it more comfortable for the lightweight Nigerian female driver. The light Nigerian female driver would be very uncomfortable in the vehicle based on the incompatibility between the package dimensions and her anthropometry.

The detailed analysis results for both the automatic and manual transmission types reveal some serious pains for the driver in her upper arm, forearm, wrist and trunk with the overall posture of the arm very unacceptable.

Figure 14 shows the same female manikin positioned in the vehicle package as above. However, the seat height (H30) value was changed from the default SAE value to the value of 340mm. As can be seen from the figure, there is an improvement in the overall RULA analysis score for both the automatic and manual transmission types from 4 to 3.

The comparison between the default SAE seat height and that recommended for the Nigerian population on the Nigerian female driver 5th percentile in weight for both the automatic and manual transmission types shows an improvement in upper arm comfort from 4 to 3 and overall arm posture from 5 to 4. The comfort levels for the forearm, wrist, wrist twist, neck, trunk, leg and the overall posture of the trunk, neck and leg remains the same for both.

Figure 15 presents a Nigerian male manikin 95th percentile in weight postured as a driver in the vehicle package based on the default SAE package proportions. The RULA analysis results give a final score of 3 for the automatic transmission which shows the need to modify the package proportions in order to make it more comfortable for the heavy Nigerian male driver. The final score of 4 for the manual transmission indicates that the heavy Nigerian male driver would be very uncomfortable in the vehicle based on the bad fit between the package proportions and his anthropometry.

The detailed analysis results for the automatic transmission shows some severe pains for the driver in his upper arm, wrist and trunk with the overall posture of the arm very intolerable. The manual transmission is also uncomfortable for the driver with pains in the trunk, wrist, forearm and upper arm. The overall postures of the arm, neck, trunk and leg are undesirable. The automatic transmission gives improved comfort than manual transmission to the heavy Nigerian male driver in the forearm, neck and the overall posture of the leg, trunk and neck.

Figure 16 shows the same male manikin postured in the vehicle package as above but changing the seat height (H30) value from the default SAE value to the value recommended for the Nigerian population. As can be seen from the figure, there is no improvement in the overall RULA analysis score for the automatic transmission, remaining the same (3) as that of the default SAE dimensions. However, the manual transmission type shows an improvement from 4 to 3.

The comparison between the default SAE seat height and that proposed for the Nigerian population on the Nigerian male driver 95th percentile in weight for the automatic transmission type indicates an improvement in upper arm comfort from 3 to 2 and overall arm posture from 4 to 3. The comfort levels for the forearm, wrist twist, neck, trunk, leg and the overall posture of the trunk, neck and leg remains the same for both. As for the manual transmission, there is an improvement in the comfort level of the neck from 2 to 1 because of a better seat height.

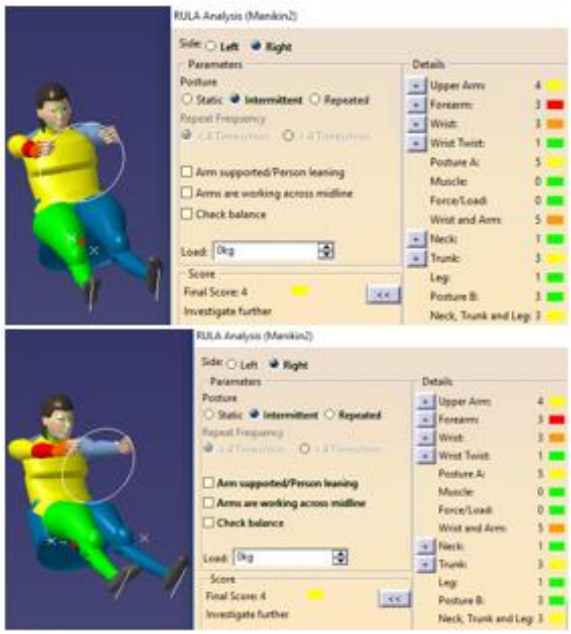

Figure 13: Nigerian Female Manikin 5th percentile in Weight Postured as a Driver in the Vehicle Package Based on SAE J1100 Package Dimensions with Automatic and Manual Transmission Selection (top and bottom images respectively)

Figure 14: Nigerian Female Manikin 5th percentile in Weight Postured as a Driver in the Vehicle Package using 340mm as the Seat Height (H30) Value with Automatic and Manual Transmission Selection (top and bottom images respectively)

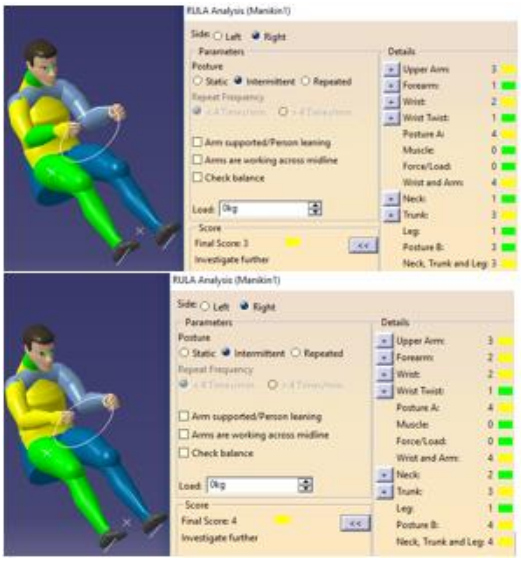

Figure 15: Nigerian Male Manikin 95th percentile in Weight Postured as a Driver in the Vehicle Package Based on SAE J1100 Package Dimensions with Automatic and Manual Transmission Selection (top and bottom images respectively)

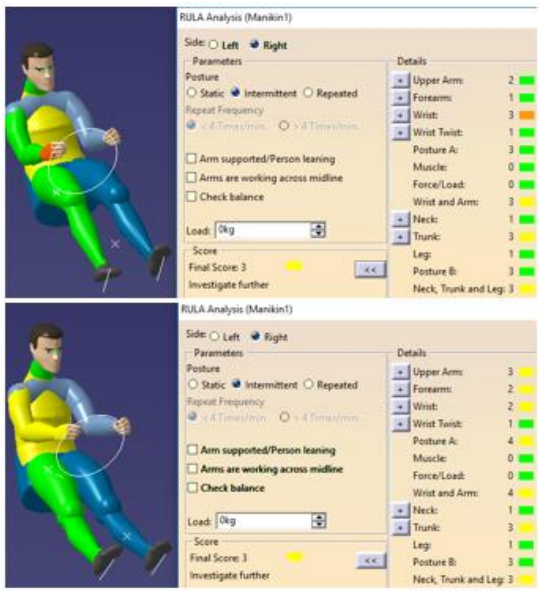

Figure 16: Nigerian Male Manikin 95th percentile in Weight Postured as a Driver in the Vehicle Package using 340mm as the Seat Height (H30) Value with Automatic and Manual Transmission Selection (top and bottom images respectively)

Erect Sitting Height

Figure 17 shows a Nigerian female manikin 5th percentile in sitting height positioned as a driver in the vehicle package based on the default SAE package dimensions. As can be seen from the RULA analysis results, the overall score for both the automatic and manual transmission types is 3 which indicates the need to adjust the package dimensions in order to make it more comfortable for the small Nigerian female driver. The small Nigerian female driver would be very uncomfortable in the vehicle based on the incompatibility between the package dimensions and her anthropometry.

The detailed analysis results for both the automatic and manual transmission types reveal some severe pains for the driver in her upper arm, forearm, wrist and trunk with the overall posture of the arm very intolerable. The automatic transmission gives improved comfort than manual transmission to the small Nigerian female driver in the upper arm. The manual transmission on the other hand gives the small Nigerian female driver better comfort than automatic transmission in the forearm.

Figure 18 shows the same female manikin positioned in the vehicle package as above, but the seat height value was changed from the default SAE value to the value of 340mm. As can be seen from the figure, there is no

improvement in the overall RULA analysis score for both the automatic and manual transmission types. They both remain the same (3) as that of the default SAE dimensions.

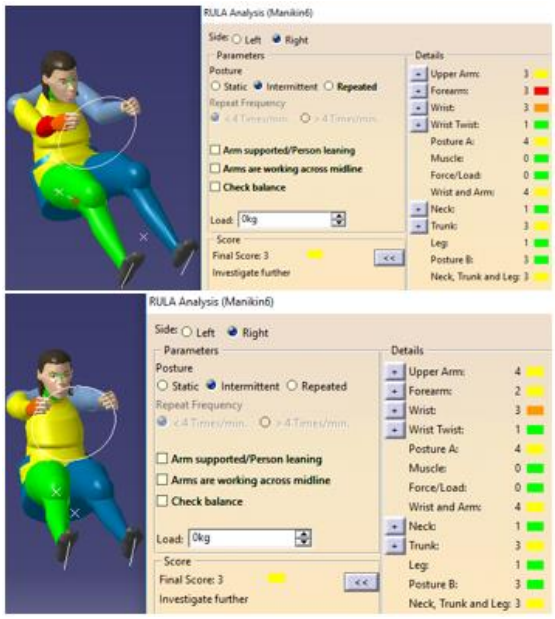

Figure 17: Nigerian Female Manikin 5th percentile in Sitting Height Postured as a Driver in the Vehicle Package Based on SAE J1100 Package Dimensions with Automatic and Manual Transmission Selection (top and bottom images respectively)

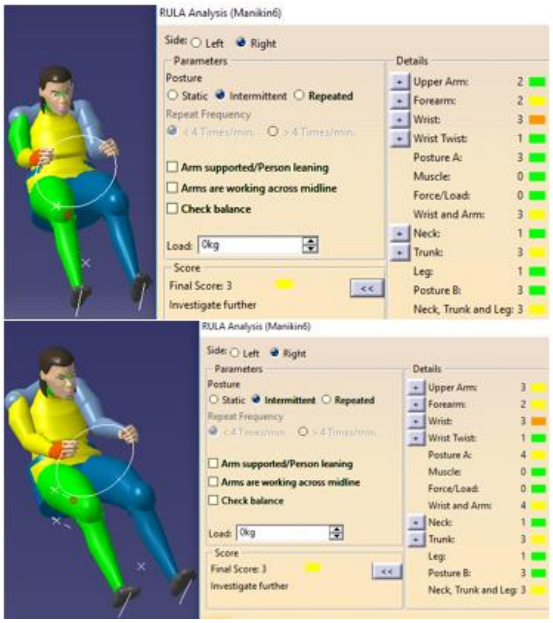

Figure 18: Nigerian Female Manikin 5th percentile in Sitting Height Postured as a Driver in the Vehicle Package using 340mm as the Seat Height (H30) Value with Automatic and Manual Transmission Selection (top and bottom images respectively)

The comparison between the default SAE seat height and that recommended for the Nigerian population on the Nigerian female driver 5th percentile in sitting height for the automatic transmission type shows an improvement in upper arm comfort from 3 to 2, forearm from 3 to 2, and overall arm posture from 4 to 3. The comfort levels for the wrist, wrist twist, neck, trunk, leg and the overall posture of the trunk, neck and leg remains the same for both. As for the manual transmission, there is an improvement in the comfort level of the upper arm from 4 to 3 which is as a result of an enhanced seat height.

Figure 19 presents a Nigerian male manikin 95th percentile in sitting height postured as a driver in the vehicle package based on the default SAE package proportions. From the RULA analysis results, the final score for both the automatic and manual transmission types is 3 which indicates the need to adjust the package dimensions in order to make it more comfortable for the big Nigerian male driver. The big Nigerian male driver would be very uncomfortable in the vehicle based on the mismatch between the package dimensions and his anthropometry.

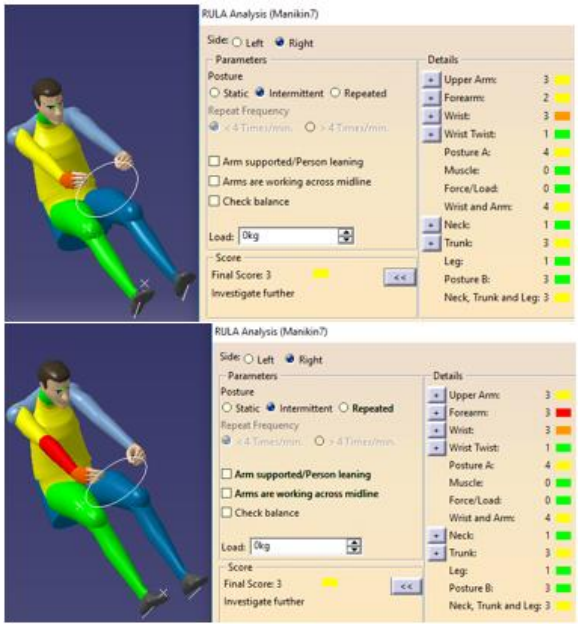

Figure 19: Nigerian Male Manikin 95th percentile in Sitting Height Postured as a Driver in the Vehicle Package Based on SAE J1100 Package Dimensions with Automatic and Manual Transmission Selection (top and bottom images respectively)

The detailed analysis results for both the automatic and manual transmission types disclose some severe pains for the driver in his

upper arm, forearm, wrist and trunk with the overall posture of the arm very unbearable. The automatic transmission provides better comfort than manual transmission to the big Nigerian male driver in the forearm.

Figure 20 shows the same male manikin postured in the vehicle package as above, but the seat height value was changed from the default SAE value to the value recommended for the Nigerian population. As can be seen from the figure, there is no improvement in the overall RULA analysis score for both the automatic and manual transmission types. They both remain the same (3) as that of the default SAE dimensions.

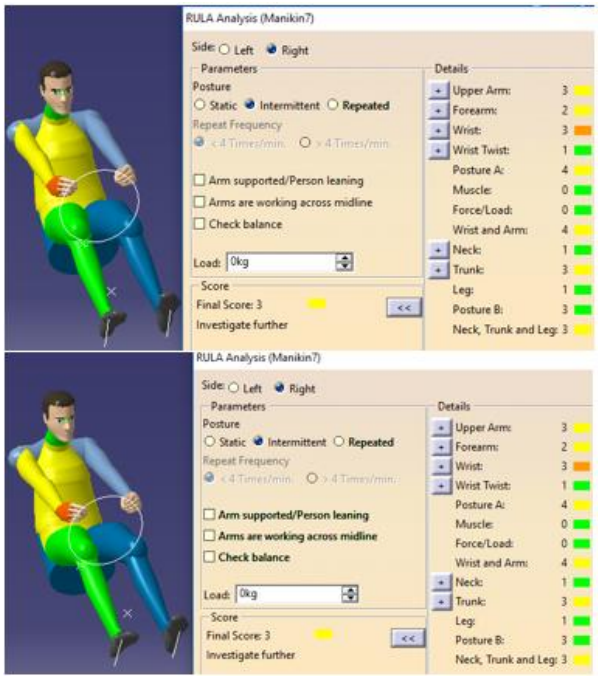

Figure 20: Nigerian Male Manikin 95th percentile in Sitting Height Postured as a Driver in the Vehicle Package using 340mm as the Seat Height (H30) Value with Automatic and Manual Transmission Selection (top and bottom images respectively)

The contrast between the default SAE seat height and that proposed for the Nigerian population on the Nigerian male driver 95th percentile in sitting height for the automatic transmission type shows the same values for all the body parts. As for the manual transmission, there is an improvement in the comfort level of the forearm from 3 to 2 as a result of a better seat height.

The above findings indicate that the selection of automatic transmission type for the short statured Nigerian female and tall statured Nigerian male does indeed improve their body and postural comfort as drivers. Also, it shows that a good seat height does enhance their postural as well as body comfort and the default SAE value is not very suitable for them. Equally, it indicates that an enhanced seat height does not provide improved comfort to them in a vehicle package fitted with manual transmission. Furthermore, it indicates that the seat dimensions established from the anthropometric data of the Nigerian population can better accommodate them compared to the SAE J1100 package seat height dimension. The choice of transmission type was found not to influence the postural and body comfort of the lightweight Nigerian female driver. However, an enhanced seat height does give her better postural as well as body comfort. As for the heavy Nigerian male driver, both the seat height and the transmission type were found to have an influence on his body and postural comfort. The seat height and transmission type were found to have little impact on body and postural comfort of the Nigerian female with low sitting height and male with high sitting height. These findings are in accordance with Reed who identified stature as the most significant anthropometric variable related to driver posture (Reed & Flannagan, 2000). Also, Porter et al. established that vehicles fitted with automatic transmissions provide more postural comfort than those with manual transmission due to the absence of clutch pedal in automatic transmissions (Porter et al., 1992). Additionally, Shi & Paul identified seating height (H30) as the most important parameter related to driving comfort in the vehicle package (Shi & Paul, 2011). Finally, several scholars have stated the unsuitability of the SAE packaging standards which are used worldwide as the standard in vehicle seat design and occupant packaging for other populations as they were developed using American population anthropometry (Bhise, 2011; Herriotts & Johnson, 2012; Porter & Porter, 2001; Summerskill et al., 2010).

Passenger Accommodation and RULA Analysis

Stature

The Nigerian female manikin 5th percentile and male 95th percentile in height positioned as front passengers in the vehicle package are shown in Figures 21 and 22 respectively. The top image represents the posturing based on

the default SAE package dimensions while the bottom image represents posturing based on the seat height (H30) value recommended for the Nigerian population. The same manikins positioned as second and third row passengers in the vehicle package are shown in Figures 23 to 30. The top images represent the selection of the right seating position, middle images center seating position and bottom images left seating position. Figures 23, 24, 27 and 28 represents posturing based on the default SAE package dimensions while figures 25, 26, 29 and 30 represents posturing based on the seat height (H30) value recommended for the Nigerian population.

As can be seen from the RULA analysis results, the overall score for both the default SAE seat height value and that proposed for the Nigerian population is 5 which indicates the need to adjust the package dimensions in order to make it more comfortable for the short female and tall male Nigerian passengers. The tall male and short female Nigerian passengers would be very uncomfortable in the vehicle based on the mismatch between the package dimensions and their anthropometry.

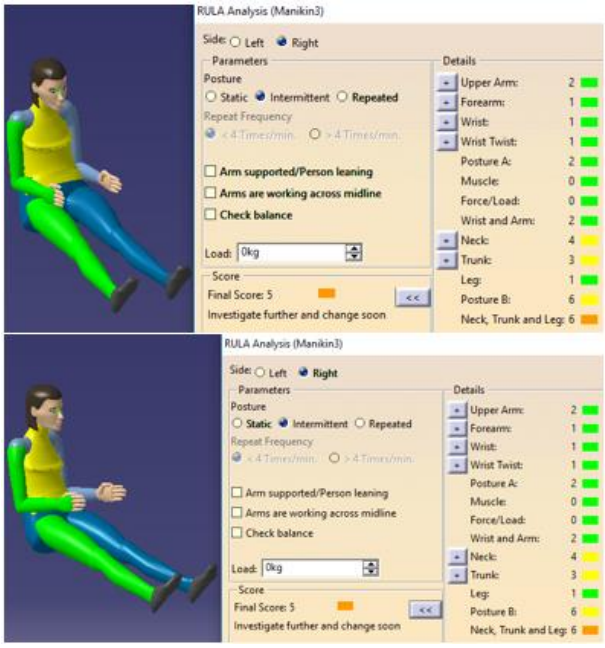

Figure 21: Nigerian Female Manikin 5th percentile in Stature Postured as a Front Row Passenger in the Vehicle Package Based on SAE J1100 Package Dimensions and using 340mm as the Seat Height (H30) Value (top and bottom images respectively)

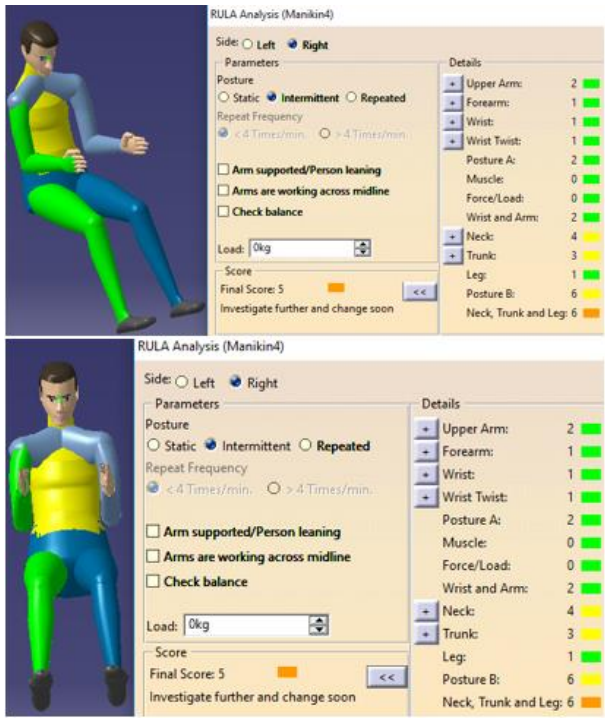

Figure 22: Nigerian Male Manikin 95th percentile in Stature Postured as a Front Row Passenger in the Vehicle Package Based on SAE J1100 Package Dimensions and using 340mm as the Seat Height (H30) Value (top and bottom images respectively)

The detailed analysis results for both the default SAE dimensions and the seat height recommended for the Nigerian population shows that the tall male and short female Nigerian passengers will experience discomfort in their neck and trunk with their overall leg, neck and trunk postures not comfortable.

Figure 23: Nigerian Female Manikin 5th percentile in Stature Postured as a Second Row Passenger in the Vehicle Package Based on SAE J1100 Package Dimensions with Right, Center and Left Seating Positions (top, middle and bottom images respectively)

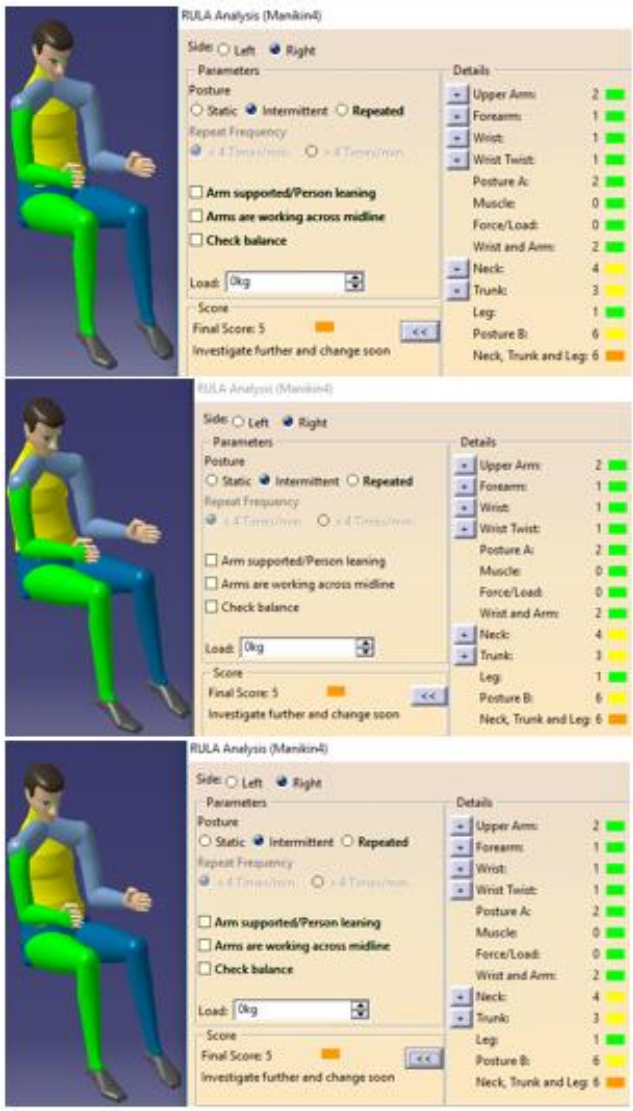

Figure 24: Nigerian Male Manikin 95th percentile in Stature Postured as a Second Row Passenger in the Vehicle Package Based on SAE J1100 Package Dimensions with Right, Center and Left Seating Positions (top, middle and bottom images respectively)

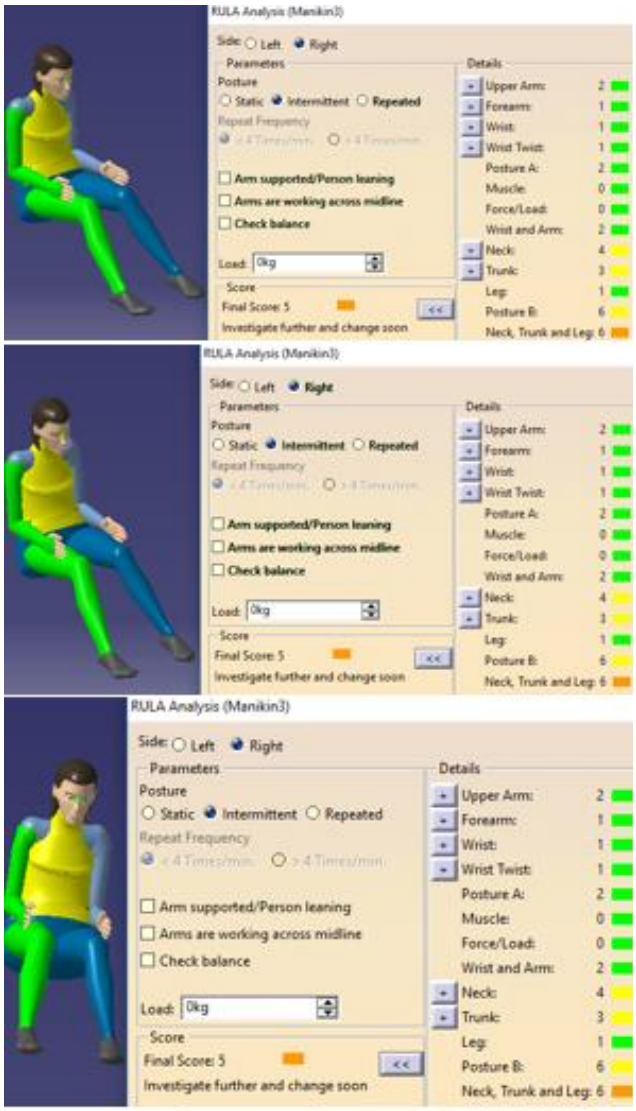

Figure 25: Nigerian Female Manikin 5th percentile in Stature Postured as a Second Row Passenger in the Vehicle Package using 340mm as the Seat Height (H30) Value with Right, Center and Left Seating Positions (top, middle and bottom images respectively)

Figure 26: Nigerian Male Manikin 95th percentile in Stature Postured as a Second Row Passenger in the Vehicle Package using 340mm as the Seat Height (H30) Value with Right, Center and Left Seating Positions (top, middle and bottom images respectively)

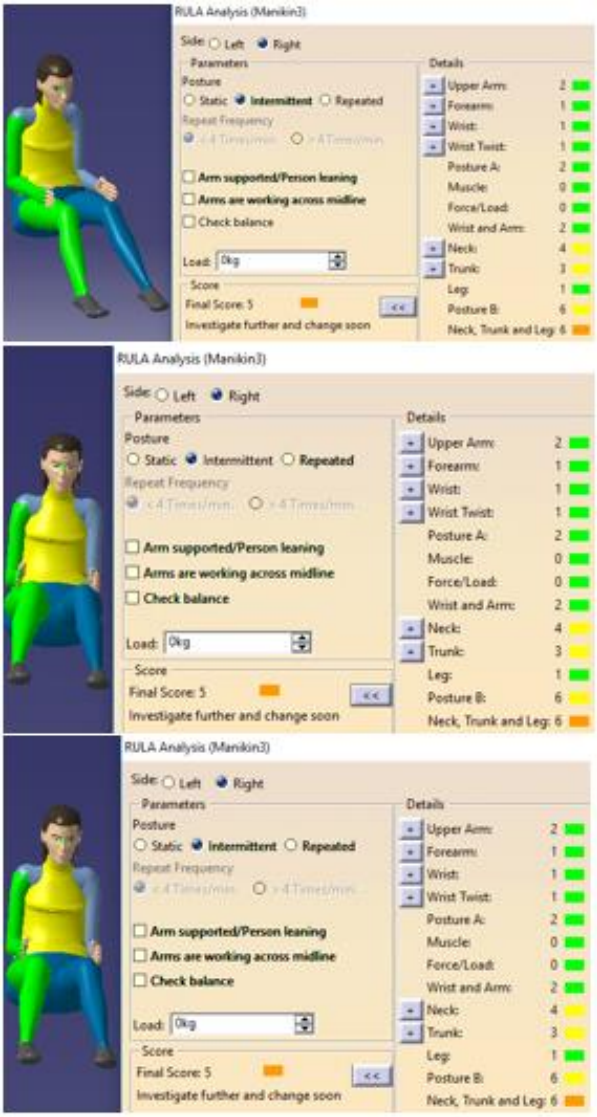

Figure 27: Nigerian Female Manikin 5th percentile in Stature Postured as a Third Row Passenger in the Vehicle Package Based on SAE J1100 Package Dimensions with Right, Center and Left Seating Positions (top, middle and bottom images respectively)

Figure 28: Nigerian Male Manikin 95th percentile in Stature Postured as a Third Row Passenger in the Vehicle Package Based on SAE J1100 Package Dimensions with Right, Center and Left Seating Positions (top, middle and bottom images respectively)

Figure 29: Nigerian Female Manikin 5th percentile in Stature Postured as a Third Row Passenger in the Vehicle Package using 340mm as the Seat Height (H30) Value with Right, Center and Left Seating Positions (top, middle and bottom images respectively)

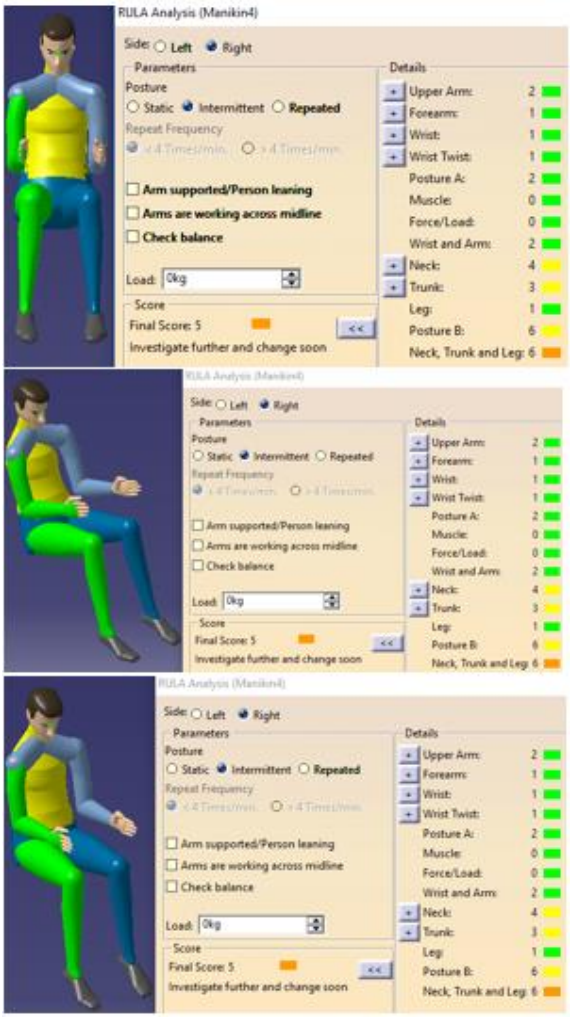

Figure 30: Nigerian Male Manikin 95th percentile in Stature Postured as a Third Row Passenger in the Vehicle Package using 340mm as the Seat Height (H30) Value with Right, Center and Left Seating Positions (top, middle and bottom images respectively)

Weight

The Nigerian female manikin 5th percentile and male 95th percentile in weight positioned as front passengers in the vehicle package are shown in Figures 31 and 32 respectively. The same manikins positioned as second and third row passengers in the vehicle package are shown in Figures 33 to 40. Figures 33, 34, 37 and 38 represents posturing based on the default SAE package dimensions while Figures 35, 36, 39 and 40 represents posturing based on the seat height (H30) value recommended for the Nigerian population.

As can be seen from the RULA analysis results, the overall score for both the default SAE seat height value and that proposed for the Nigerian population for the 95th percentile male passenger is 5 while that of the 5th

percentile female passenger is 4. This indicates the need to adjust the package dimensions in order to make it more comfortable for the light female and heavy male Nigerian passengers. The heavy male and light female Nigerian passengers would be very uncomfortable in the vehicle based on the bad fit between the package dimensions and their anthropometry.

The detailed analysis results for both the default SAE dimensions and the seat height recommended for the Nigerian population shows that the heavy male Nigerian passenger will experience discomfort in his neck and trunk with his overall leg, neck and trunk postures not comfortable. The light Nigerian female passenger will feel some pains in her trunk with her general leg, neck and trunk postures unbearable.

The comparison between the default SAE seat height and that recommended for the Nigerian population on the Nigerian female passenger 5th percentile in weight for the front passenger shows an improvement in trunk comfort from 4 to 3 and overall leg, neck and trunk posture from 5 to 3 as a result of an enhanced seat height.

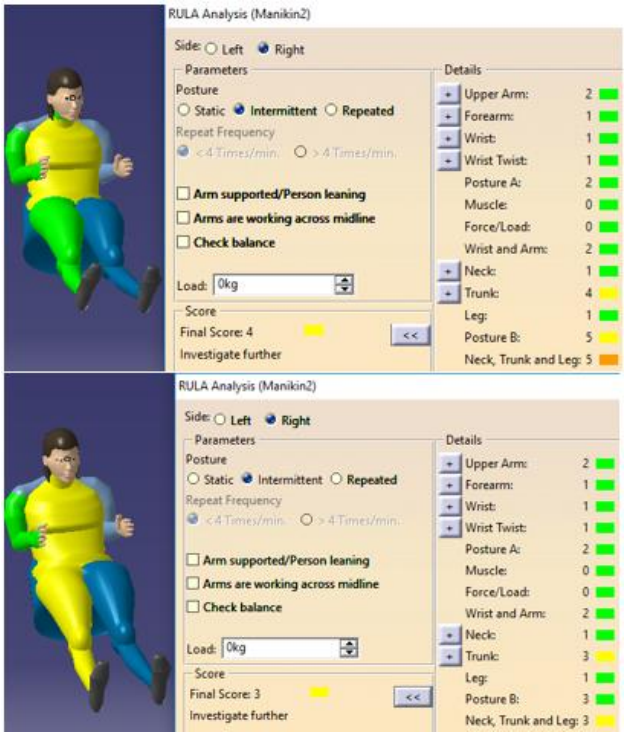

Figure 31: Nigerian Female Manikin 5th percentile in Weight Postured as a Front Row Passenger in the Vehicle Package Based on SAE J1100 Package Dimensions and using 340mm as the Seat Height (H30) Value (top and bottom images respectively)

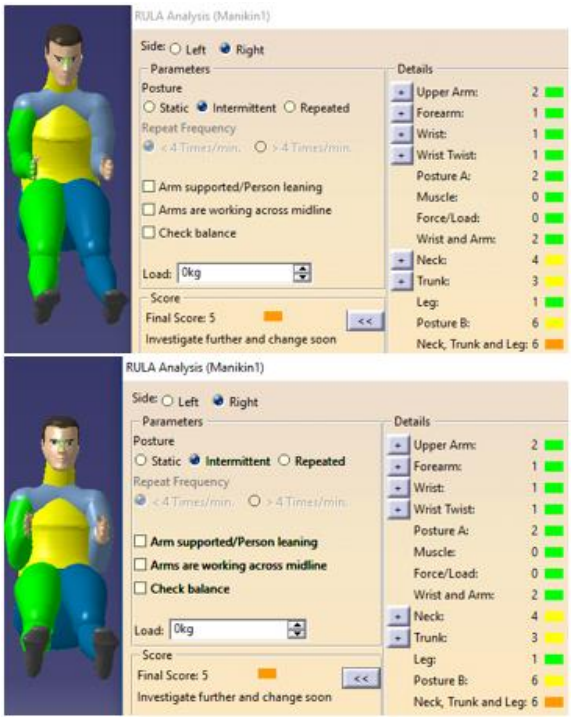

Figure 32: Nigerian Male Manikin 95th percentile in Weight Postured as a Front Row Passenger in the Vehicle Package Based on SAE J1100 Package Dimensions and using 340mm as the Seat Height (H30) Value (top and bottom images respectively)

Figure 33: Nigerian Female Manikin 5th percentile in Weight Postured as a Second Row Passenger in the Vehicle Package Based on SAE J1100 Package Dimensions with Right, Center and Left Seating Positions (top, middle and bottom images respectively)

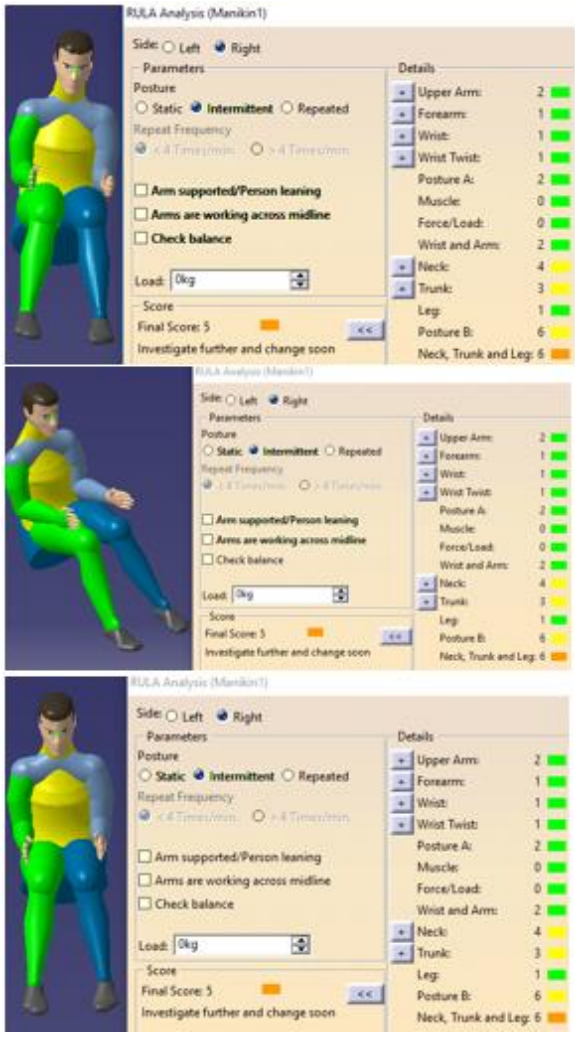

Figure 34: Nigerian Male Manikin 95th percentile in Weight Postured as a Second Row Passenger in the Vehicle Package Based on SAE J1100 Package Dimensions with Right, Center and Left Seating Positions (top, middle and bottom images respectively)

Figure 35: Nigerian Female Manikin 5th percentile in Weight Postured as a Second Row Passenger in the Vehicle Package using 340mm as the Seat Height (H30) Value with Right, Center and Left Seating Positions (top, middle and bottom images respectively)

Figure 36: Nigerian Male Manikin 95th percentile in Weight Postured as a Second Row Passenger in the Vehicle Package using 340mm as the Seat Height (H30) Value with Right, Center and Left Seating Positions (top, middle and bottom images respectively)

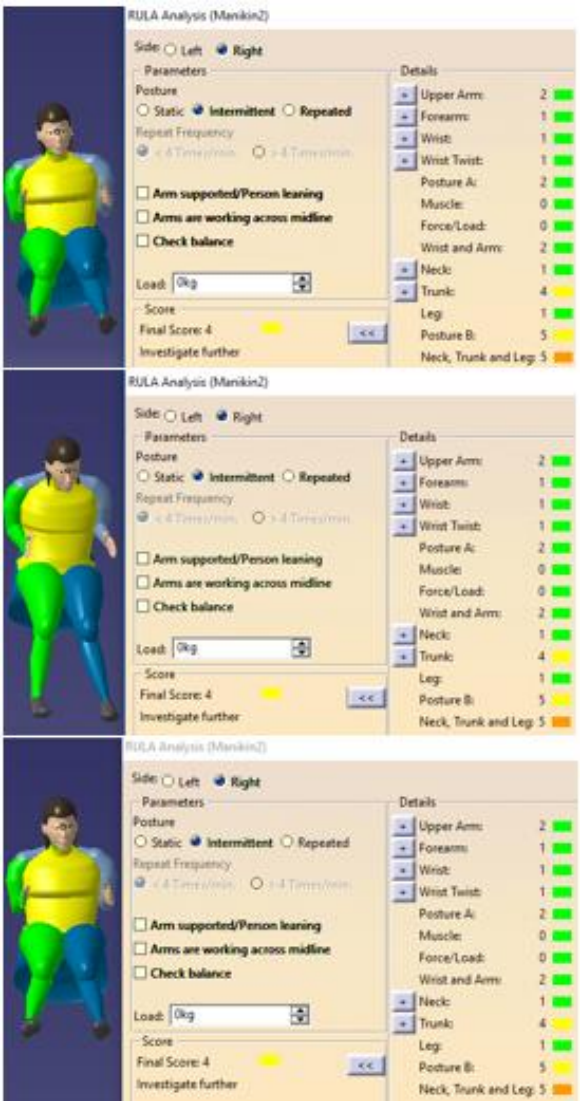

Figure 37: Nigerian Female Manikin 5th percentile in Weight Postured as a Third Row Passenger in the Vehicle Package Based on SAE J1100 Package Dimensions with Right, Center and Left Seating Positions (top, middle and bottom images respectively)

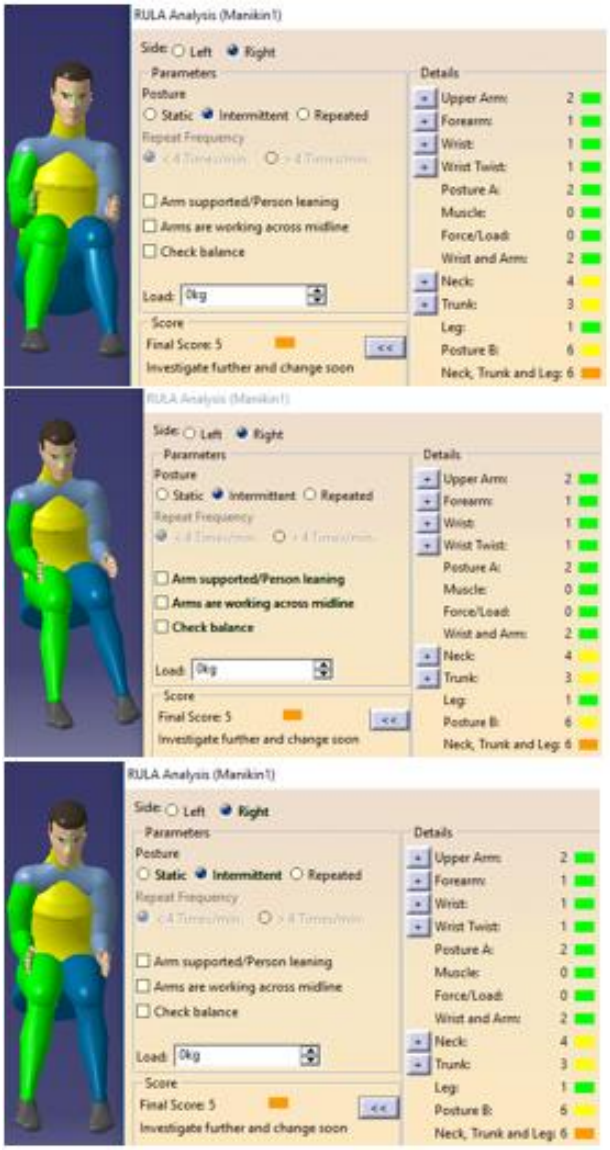

Figure 38: Nigerian Male Manikin 95th percentile in Weight Postured as a Third Row Passenger in the Vehicle Package Based on SAE J1100 Package Dimensions with Right, Center and Left Seating Positions (top, middle and bottom images respectively)

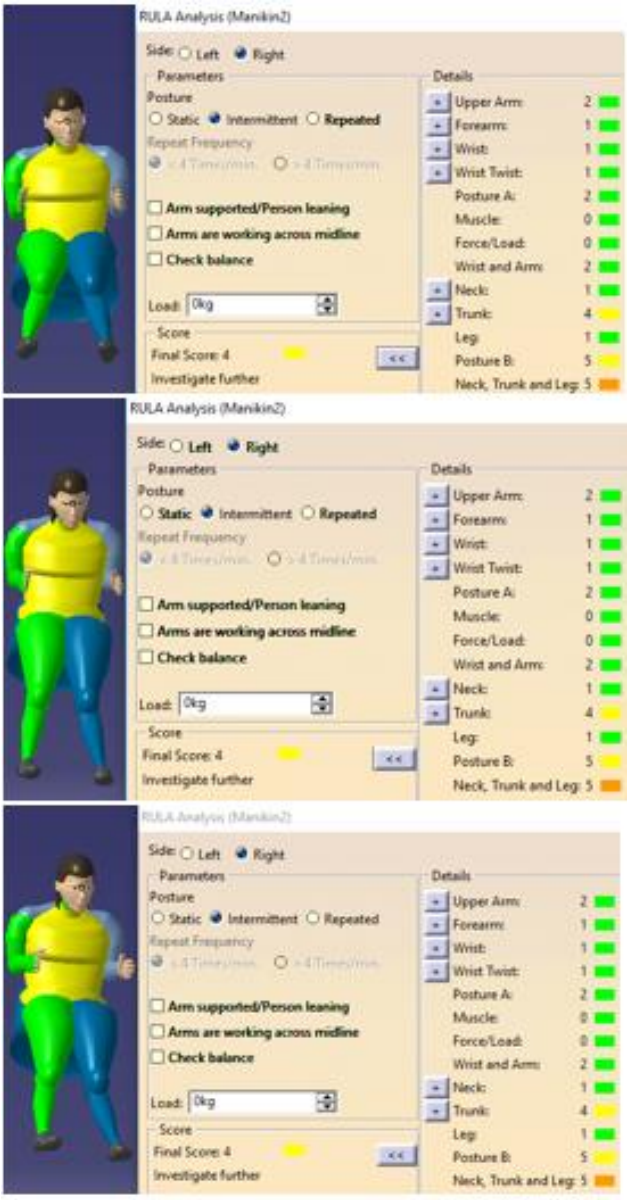

Figure 39: Nigerian Female Manikin 5th percentile in Weight Postured as a Third Row Passenger in the Vehicle Package using 340mm as the Seat Height (H30) Value with Right, Center and Left Seating Positions (top, middle and bottom images respectively)

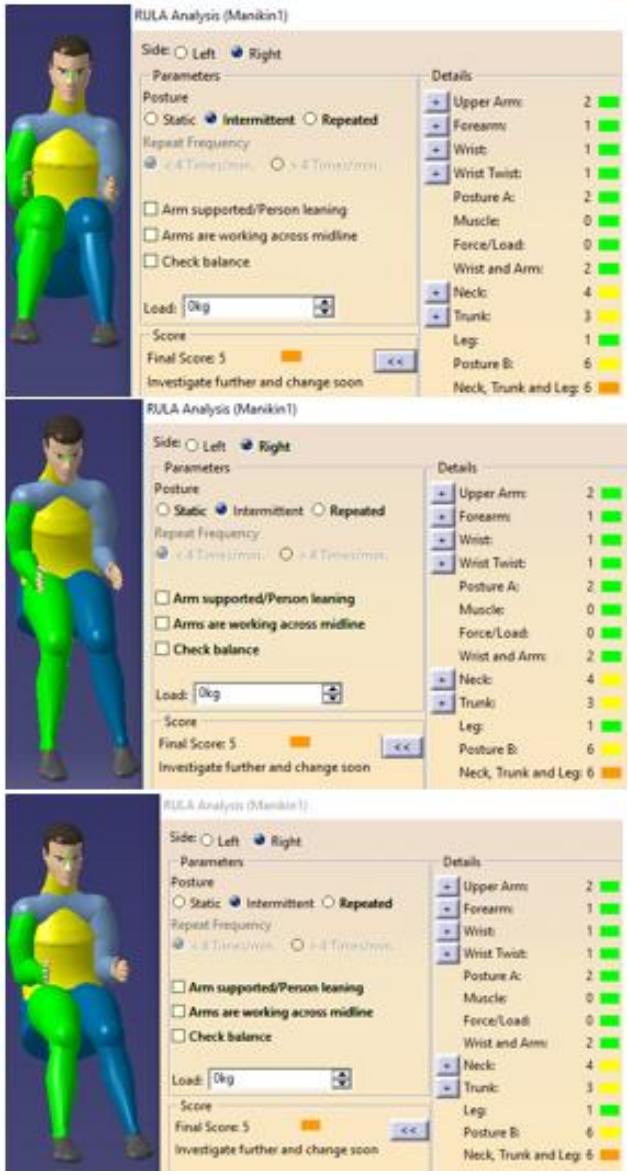

Figure 40: Nigerian Male Manikin 95th percentile in Weight Postured as a Third Row Passenger in the Vehicle Package using 340mm as the Seat Height (H30) Value with Right, Center and Left Seating Positions (top, middle and bottom images respectively)

Erect Sitting Height

The Nigerian female manikin 5th percentile and male 95th percentile in sitting height positioned as front passengers in the vehicle package are shown in Figures 41 and 42 respectively. The same manikins positioned as second and third row passengers in the vehicle package are shown in Figures 43 to 50. Figures 43, 44, 47 and 48 represents posturing based on the default SAE package dimensions while Figures 45, 46, 49 and 50 represents posturing based on the seat height (H30) value recommended for the Nigerian population.

As can be seen from the RULA analysis results, the overall score for both the default SAE seat height value and that proposed for the Nigerian population is 5 which indicates the need to adjust the package dimensions in order to make it more comfortable for the small female and big male Nigerian passengers. The big male and small female Nigerian passengers would be very uncomfortable in the vehicle because of the incompatibility between the package dimensions and their anthropometry.

The detailed analysis results for both the default SAE dimensions and the seat height recommended for the Nigerian population shows that the big male and small female Nigerian passengers will experience discomfort in their neck and trunk with their overall leg, neck and trunk postures not comfortable.

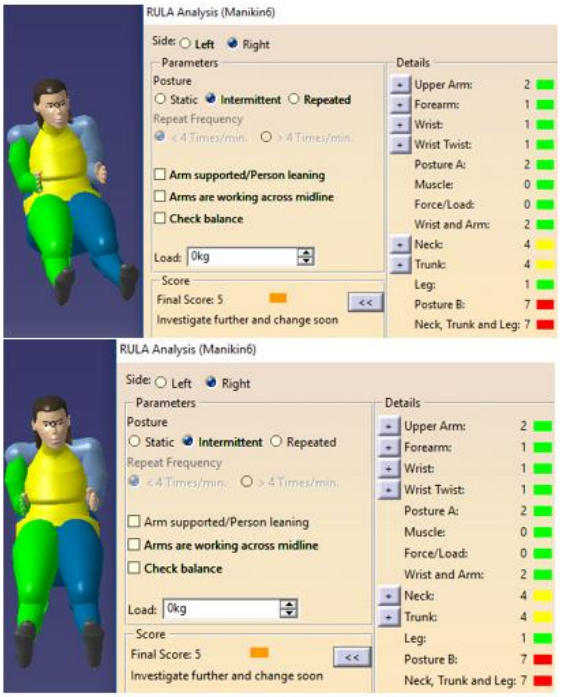

Figure 41: Nigerian Female Manikin 5th percentile in Sitting Height Postured as a Front Row Passenger in the Vehicle Package Based on SAE J1100 Package Dimensions and using 340mm as the Seat Height (H30) Value (top and bottom images respectively)

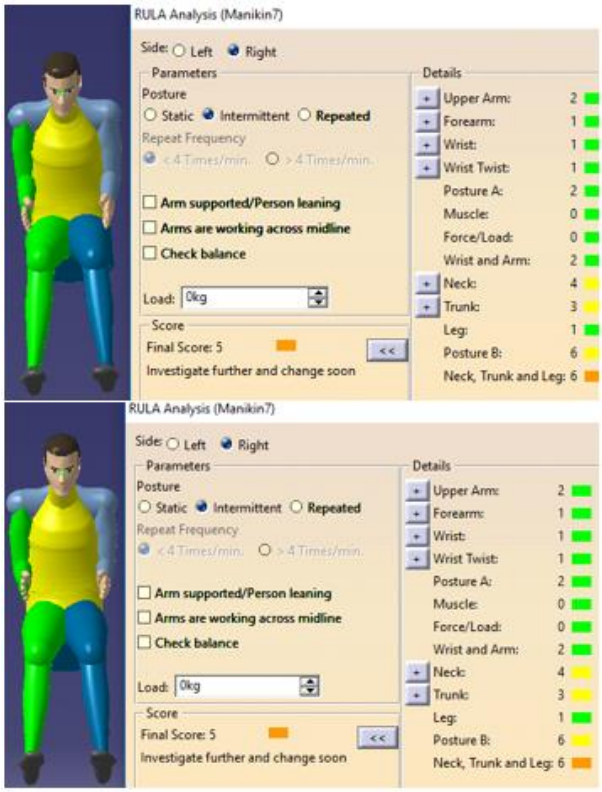

Figure 42: Nigerian Male Manikin 95th percentile in Sitting Height Postured as a Front Row Passenger in the Vehicle Package Based on SAE J1100 Package Dimensions and using 340mm as the Seat Height (H30) Value (top and bottom images respectively)

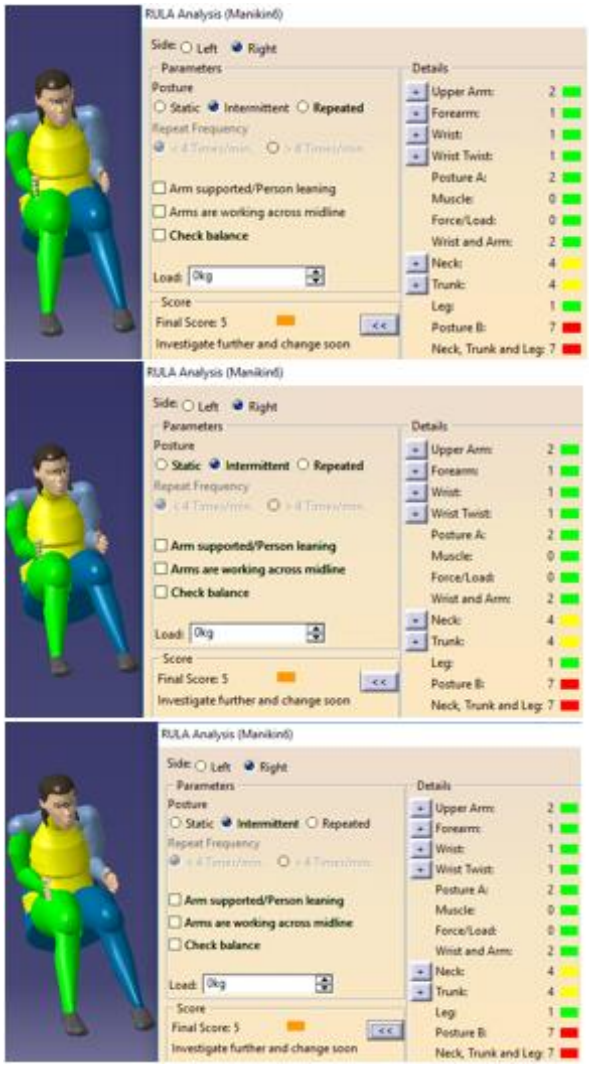

Figure 43: Nigerian Female Manikin 5th percentile in Sitting Height Postured as Second Row Passenger in the Vehicle Package Based on SAE J1100 Package Dimensions with Right, Center and Left Seating Positions (top, middle and bottom images respectively)

Figure 44: Nigerian Male Manikin 95th percentile in Sitting Height Postured as a Second Row Passenger in the Vehicle Package Based on SAE J1100 Package Dimensions with Right, Center and Left Seating Positions (top, middle and bottom images respectively)

Figure 45: Nigerian Female Manikin 5th percentile in Sitting Height Postured as Second Row Passenger in the Vehicle Package using 340mm as the Seat Height (H30) Value with Right, Center and Left Seating Positions (top, middle and bottom images respectively)

Figure 46: Nigerian Male Manikin 95th percentile in Sitting Height Postured as a Second Row Passenger in the Vehicle Package using 340mm as the Seat Height (H30) Value with Right, Center and Left Seating Positions (top, middle and bottom images respectively)

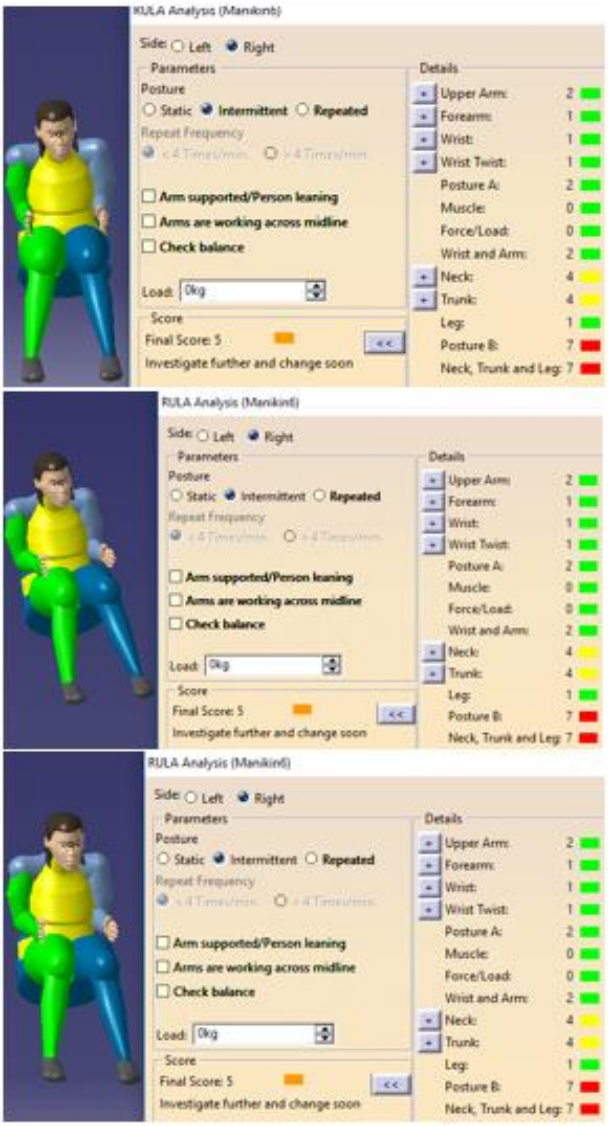

Figure 47: Nigerian Female Manikin 5th percentile in Sitting Height Postured as a Third Row Passenger in the Vehicle Package Based on SAE J1100 Package Dimensions with Right, Center and Left Seating Positions (top, middle and bottom images respectively)

Figure 48: Nigerian Male Manikin 95th percentile in Sitting Height Postured as a Third Row Passenger in the Vehicle Package Based on SAE J1100 Package Dimensions with Right, Center and Left Seating Positions (top, middle and bottom images respectively)

Figure 49: Nigerian Female Manikin 5th percentile in Sitting Height Postured as a Third Row Passenger in the Vehicle Package using 340mm as the Seat Height (H30) Value with Right, Center and Left Seating Positions (top, middle and bottom images respectively)

Figure 50: Nigerian Male Manikin 95th percentile in Sitting Height Postured as a Third Row Passenger in the Vehicle Package using 340mm as the Seat Height (H30) Value with Right, Center and Left Seating Positions (top, middle and bottom images respectively)

The SAE package dimensions were found to be very unsuitable to the short female, tall male, female with low seating height, male with high seating height and heavy male Nigerian passengers in the front, second and third passenger rows as well as the right, left and center seating positions. The enhanced seat height also does not give them better postural and body comfort because of the effect of other SAE J1100 package dimensions. It is a bit more suitable to the light Nigerian female passenger and an improved seat height does give her better body and postural comfort as a front passenger. These findings are in stark contrast to the ones above in respect to drivers even though the same manikins were used for both set of analysis. This is in accordance to Shi & Paul who established that

in contrast to the driver posture which is restricted by the position of the hands on the steering wheel and the foot on the pedals, the passenger posture is not restricted by anything (Shi & Paul, 2011). This might explain why the RULA score for the passengers for our analysis is uniform for five out of the six manikins.

Seat Design

The ergonomic automotive seat suitable for the Nigerian population designed using CATIA V5 software is shown in Figure 51 below.

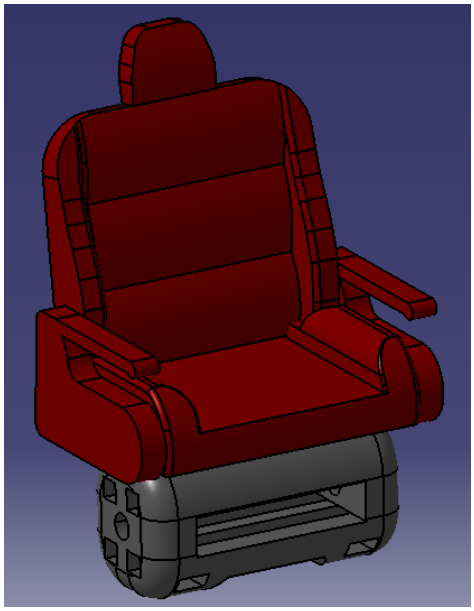

Figure 51: 3D Model of the Designed Seat

Seat Manikin Positioning and RULA Analysis

Popliteal Height Sitting

Figure 52 shows a Nigerian female manikin 5th percentile in seated popliteal height positioned on the ergonomic automotive seat designed for the Nigerian population based on their sitting anthropometry. As can be seen from the RULA Analysis results, the seat is very comfortable for the small Nigerian female having a low seated popliteal height with an acceptable RULA score of 2. The detailed analysis results show good comfort levels for all the body parts.

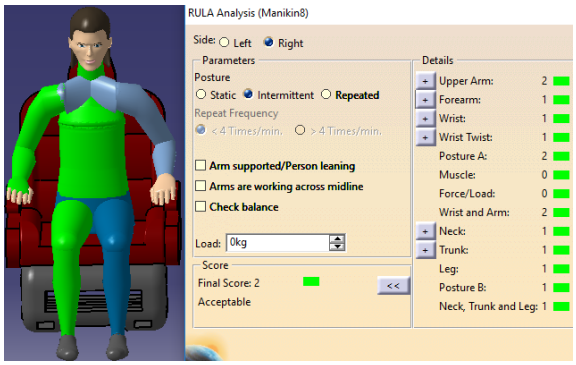

Figure 52: Nigerian Female Manikin 5th percentile in Seated Popliteal Height Postured on the Ergonomic Automotive Seat Designed for the Nigerian Population

Hip Width Sitting

Figure 53 presents a Nigerian female manikin 95th percentile in seated hip width positioned on the ergonomic automotive seat designed for the Nigerian population based on their sitting anthropometry. As can be seen from the RULA Analysis results, the seat is very comfortable for the big Nigerian female having a large seated hip width with an acceptable RULA score of 2. The detailed analysis results show good comfort levels for all the body parts.

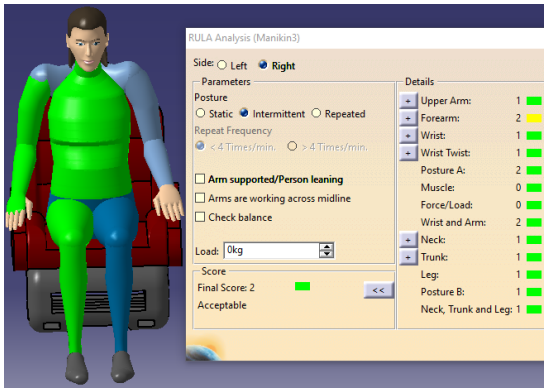

Figure 53: Nigerian Female Manikin 95th percentile in Seated Hip Width Postured on the Ergonomic Automotive Seat Designed for the Nigerian Population

Buttock-Popliteal Length

Figure 54 shows a Nigerian female manikin 5th percentile in buttock popliteal length positioned on the ergonomic automotive seat designed for the Nigerian population based on their sitting anthropometry. As can be seen from the RULA Analysis results, the seat is very comfortable for the Nigerian female having a short buttock popliteal length with

an acceptable RULA score of 2. The detailed analysis results show good comfort levels for all the body parts.

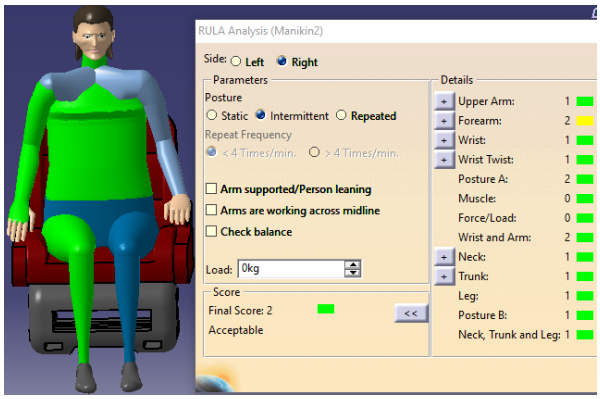

Figure 54: Nigerian Female Manikin 5th percentile in Buttock Popliteal Length Postured on the Ergonomic Automotive Seat Designed for the Nigerian Population

Interscye Distance

Figure 55 shows a Nigerian male manikin 95th percentile in Interscye breadth positioned on the ergonomic automotive seat designed for the Nigerian population based on their sitting anthropometry. As can be seen from the RULA Analysis results, the seat is very comfortable for the Nigerian male having a wide Interscye breadth with an acceptable RULA score of 2. The detailed analysis results show good comfort levels for all the body parts.

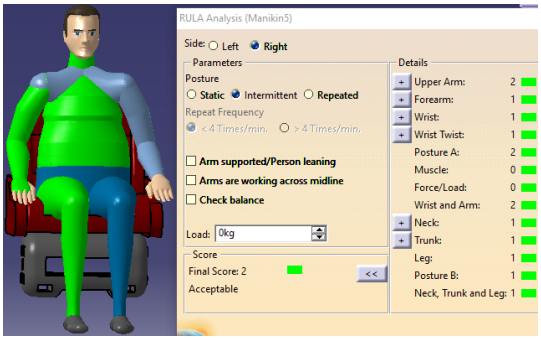

Figure 55: Nigerian Male Manikin 95th percentile in Interscye Distance Postured on the Ergonomic Automotive Seat Designed for the Nigerian Population

Shoulder Height Sitting

Figure 56 shows a Nigerian male manikin 95th percentile in seated shoulder height positioned on the ergonomic automotive seat designed for the Nigerian population based on their sitting anthropometry. As can be seen from the RULA Analysis results, the seat is very comfortable for the Nigerian male having a high seated shoulder height with an acceptable RULA score of 2. The detailed analysis results show acceptable comfort levels for all the body parts.

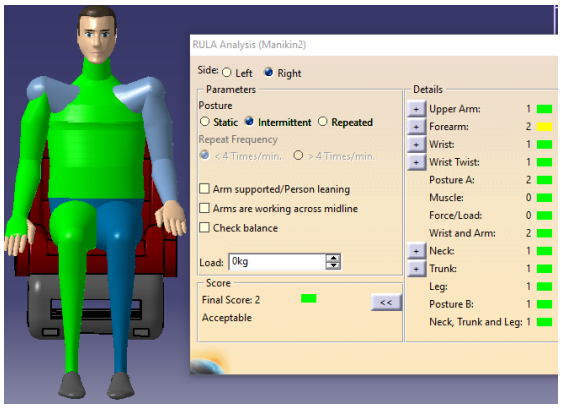

Figure 56: Nigerian Male Manikin 95th percentile in Seated Shoulder Height Postured on the Ergonomic Automotive Seat Designed for the Nigerian Population

Figure 57 presents a Nigerian female manikin 5th percentile in seated shoulder height positioned on the ergonomic automotive seat designed for the Nigerian population based on their sitting anthropometry. As can be seen from the RULA Analysis results, the seat is very comfortable for the Nigerian female having a low seated shoulder height with an acceptable RULA score of 2. The detailed analysis results show good comfort levels for all the body parts.

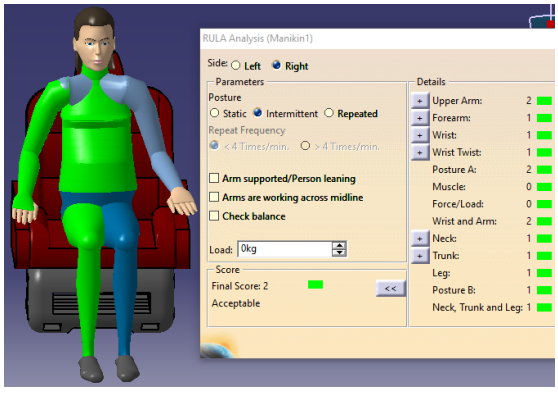

Figure 57: Nigerian Female Manikin 5th percentile in Seated Shoulder Height Postured on the Ergonomic Automotive Seat Designed for the Nigerian Population

Shoulder Bideltoid Breadth

Figure 58 shows a Nigerian male manikin 95th percentile in shoulder Bideltoid breadth positioned on the ergonomic automotive seat designed for the Nigerian population based on their sitting anthropometry. As can be seen from the RULA Analysis results, the seat is very comfortable for the Nigerian male having a wide shoulder Bideltoid breadth with an acceptable RULA score of 2. The detailed analysis results show good comfort levels for all the body parts.

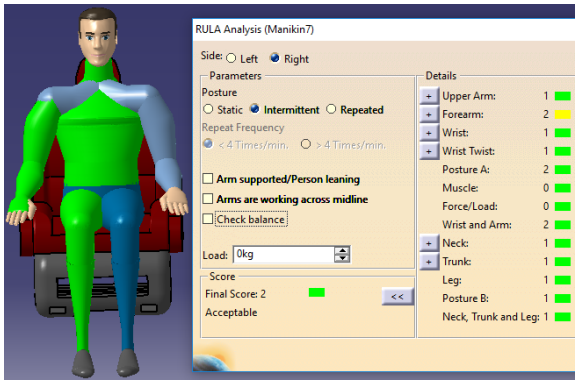

Figure 58: Nigerian Male Manikin 95th percentile in Shoulder Bideltoid Breadth Postured on the Ergonomic Automotive Seat Designed for the Nigerian Population

The RULA analysis results for the seven Nigerian manikins lying in the limits of the anthropometric variables used to design the ergonomic automotive seat for the Nigerian population shows acceptable comfort levels for all the seven manikins in all the body parts. This indicates that the automotive seat dimensions established for the Nigerian population based on their sitting anthropometry does indeed fit and accommodate a huge variety of the Nigerian population despite the variability in their anthropometric dimensions.

CONCLUSION

The SAE J1100 package dimensions were found to be unsuitable for the Nigerian population with overall RULA scores between 3 to 6 for drivers and 4 to 5 for passengers. However, the choice of automatic transmission was found to offer better body and postural comfort compared to manual transmission for some of the Nigerian driving population with a difference of 1 to 3 in both the individual body parts and total RULA scores. Also, an enhanced seat height was found to provide improved body and postural comfort for some of the Nigerian driving population with a difference of 1 in both the final and individual body parts RULA scores. On the other hand, an improved seat height was found not to give enhanced body and postural comfort for most of the Nigerian passenger population due to the effect of other SAE J1100 package dimensions with uniform overall RULA scores of 4 and 5. Finally, the seat designed for the Nigerian population proves to fit and accommodate them comfortably with acceptable RULA scores of 2 for all the seven Nigerian manikins analyzed.

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COMPETING INTERESTS

There is no conflict of interest.

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