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ANTHROPOMETRIC COMPARISON OF ANTHROPOMETRIC TEST DEVICE (ATD) AND NIGERIAN FEMALE ADULT

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ABSTRACT
Anthropometric test device (ATD) is surrogate used in automotive crash testing. Female ATDs used worldwide in the evaluation of vehicle safety performance was produced based on anthropometry of U.S. population. This work is aimed at assessing the difference between the anthropometric dimensions of Nigerian female adults from three major ethnic groups and ATDs, utilizing data reported in the literature. The comparison revealed differences varying from 0.5% to 2.1% in stature and 1.5% to 16.7% in the body weight. Small female and mid size female ATD could represent Igbo female because the difference in both stature and weight is within 2%. It was also found that female ATDs could not represent Hausa and Yoruba female population. ATD stature and weight targets differ from the Nigerian female population by less than 11 percentile points. This will lead to different injury outcomes in vehicular crashes. Vehicles certified using the ATD might not be safer for Nigerian female occupant. Therefore, car designers and manufactures need to consider the anthropometric differences in their future designs to ensure that vehicle used by Nigerians are evaluated using ATDs that truly represent the population.
Keywords: Anthropometry; ATD; Crash test; Vehicle safety

INTRODUCTION

Anthropometric test devices have been the tools employed in crash testing of vehicle to evaluate occupant injury severities for various crash configurations. They are designed to represent human dimensions, shape, weight and articulation of joints. Dummies are instrumented to measure the accelerations, moments and forces experienced by head, neck, chest and femur during crash. Biomechanical responses of the dummy are compared with standards to ensure that vehicle is safe for the occupants. The most commonly used ATDs are Hybrid III family which include Hybrid III 5th percentile female shown in Figure 1. It is intended to be representative of typical U.S. 5th percentile female in stature, weight and shape (Reed and Rupp 2013).

Figure 1 Hybrid III 5th Percentile Female ATD (Humanetics 2017)

Various safety standards have been established around the world with aim of ensuring safety for the vehicle occupants. New cars produced most undergo crash test to satisfy certain safety requirements for the occupant at various impact conditions.

New Car Assessment Programme (NCAP) requires vehicle to pass certain safety requirements in frontal, offset and side impacts. Injury threshold values for various human body regions were set for given impact condition. Some countries such as China and Korea have established NCAP that suit their safety requirements. Vehicle crash testing with Hybrid III 5th percentile female is currently a requirement of Euro NCAP, US NCAP, China NCAP and Korea NCAP (Isa *et al.,* 2016).

This implies that there is concern about injuries sustained by small female in vehicle crashes. There are recently efforts by automobile stakeholders and Nigerian government of producing made in Nigerian vehicles. Some companies have started assembling cars sold in Nigeria. To provide effective protection in car crashes, Nigerian female adults' anthropometry must be taken in to consideration in evaluating safety performance of vehicles used by Nigerian occupants.

Nigeria depends on imported used and new vehicles that are produced based on safety standards of developed world. Safety performance of these vehicles is evaluated using ATDs representing mainly U.S. population (Cao *et al.,* 2015). These ATDs might provide injury parameters such as head injury criteria and chest acceleration that are different from that of Nigerian vehicle occupants because of differences in anthropometric characteristics. There have been many studies recently on comparing various populations of the world and ATDs in order to determine the validity of using the ATDs in crash test. Reed and Rupp (2013) compare current U.S. adults' anthropometry with Hybrid III dummy dimensions. It was found that small and midsize female ATD could not represent current U.S. population. Isa *et al.,* (2016) studied the difference in anthropometry between ATD and Malaysian adults. It was concluded that current ATDs do not represent Malaysian small female adult. Chinese female adults were found to be different from ATDs in terms of stature and body weight (Cao *et al.,* 2015). For child vehicle occupants however, Serre *et al.,* (2006) revealed that, French 3 and 6 year old child anthropometry differ from crash dummies for various dimensions. A significant difference in anthropometric dimensions between three year old Nigerian child and ATDs were also determined by Rafukka *et al.,* (2016). There is no study on assessment of differences between Nigerian female adult and ATDs despite the fact that Nigeria is one of the major vehicle users in Africa. This work is aimed at assessing the difference in anthropometry between Nigerian female adult and ATDs in order to determine the validity of using the dummies in crash testing of vehicles used by Nigerians.

MATERIALS AND METHODS

Data Source

The data used in this study was obtained from previous studies in which stature and body weight of three major ethnic groups in Nigeria was published. This is done in order to ensure that every part of the country is represented. Studies on anthropometric comparison between ATDs and female adults for Malaysia, U.S. and China were carried out using data from national anthropometric database (Reed and Rupp 2013; Cao *et al.*, 2015; Isa et *al.,* 2016). However, there is still no anthropometric database for Nigerian population (Onawumi and Lucas 2012; Samuel *et al.,* 2016). Studies for anthropometric data of Nigerian adults especially for weight and stature were for medical research involving blood pressure (Anyanwu *et al.,* 2010; Chinedu and Emiloju 2014; Chukwujekwu *et al.,* 2014; Okamkpa *et al.,* 2016). Some research are for ergonomic applications for school furniture and vehicle seat (Onawumi and Lucas 2012; Ismaila *et al.,* 2013; Samuel *et al.,* 2016). Other works deal with studying the anthropometric characteristics of various ethnic groups (Oladipo *et al.,* 2005; Goon *et al.,* 2011; Taura 2012; Egbe *et al.,* 2014; Ogunlade and Adalumo 2015; Alabi *et al.,* 2017). One study that is recent and has high number of subjects was selected for each of the three major ethnic groups of Hausa, Igbo and Yoruba. Another study by Alabi *et al.,* (2017) further confirmed the stature of female adults from three ethnic groups. The difference in stature from Alabi *et al.,* (2017) and the one from the three selected studies was found to be within 1.2%. All the three studies show a significant difference in mean between male and female subjects in both stature and weight (P-value $\leq$ 0.05). This study is limited to weight and stature because the two parameters are the reference dimensions that significantly affects the biomechanical response of the ATDs. Other dimensions of ATD are derived from individual that has similar size with the reference dimensions. Number of samples from the three studies were in accordance with recommendation of WHO which requires anthropometric studies to have at least 200 samples (Bridger 2003). Table 1 shows stature and body weight of Nigerian female adults from the three selected studies. The data was obtained in terms of mean and standard deviation.

Table 1 Anthropometric data of Nigerian female adults

Source	Anthropometry	Age	No. of Subject	Mean	Standard deviation
(Taura 2012) (Hausa)	Stature (mm)	18-60	504	1600	±68
	Weight (kg)	18-60	504	59.1	±12.3
(Okamkpa *et al.,* 2016) (Igbo)	Stature (mm)	28-74	282	1602.9	±74.3
	Weight (kg)	28-74	282	63.3	±9.7
(Ogunlade and Adalumo 2015) (Yoruba)	Stature (mm)	18-41	242	1620	±70
	Weight (kg)	18-41	242	58.5	±9.5

The weight and stature of small female ATDs were obtained from (Mertz *et al.*, 2001). Because the midsize female ATD is not yet available, Nigerian midsize female anthropometry was compared with 50th percentile U.S. female from Schneider *et al.,* (1983) who derives data of U.S. people from sources similar to those used for Hybrid III dummy.

Data Analysis

Various percentiles can be computed using mean and standard deviation because linear dimensions of the human body are normally distributed (Pheasant and Haslegrave 2016). Though body weight shows modest skew distribution in some populations, the errors of approximating it to normal distribution are considered negligible (Pheasant and Haslegrave 2016). Thus, assuming normal distribution, the 5th and 50th percentiles were calculated using the equation:

$$X = \mu + Z\sigma \quad \text{(i)}$$

Where μ is the mean, Z is the value from standard normal distribution and σ is the standard deviation. Small (5th) and mid size (50th) female percentiles for each of the three ethnic groups was computed using equation (i) by substituting the values of mean and standard deviation from Table 1. Z values of the 5th and 95th percentiles were obtained from the standard normal distribution table.

The percentage difference between Nigerian female adults and ATDs was calculated as follows:

$$\text{Percentage difference (\% diff.)} = \frac{Nigerian\ female\ adult\ data - ATD\ data}{ATD\ data} \times 100 \quad \text{(ii)}$$

RESULTS

The anthropometric differences between small and mid size Nigerian female and corresponding ATDs are as presented in Table 2. Negative value indicates that Nigerian female dimensions are lower than reference ATDs.

Table 2 Anthropometric differences between Nigerian female adult and ATD

Variables	Small female ATD	Small female (Hausa)	%diff. (%)	Midsize -female ATD	Mid size female (Hausa)	%diff. (%)
Stature (mm)	1513.0	1488.1	-1.6	1618.0	1600.0	-1.1
Weight (kg)	46.7	38.9	-16.7	62.3	59.1	-5.1

	Small Female ATD	Small female (Igbo)	%diff. (%)	Midsize -female ATD	Mid size female (Igbo)	%diff. (%)
Stature (mm)	1513.0	1480.7	-2.1	1618.0	1602.9	-0.9
Weight (kg)	46.7	47.4	1.5	62.3	63.3	1.6

	Small Female ATD	Small female (Yoruba)	%diff. (%)	Midsize -female ATD	Mid size female (Yoruba)	%diff. (%)
Stature (mm)	1513.0	1504.9	-0.5	1618.0	1620.0	0.1
Weight (kg)	46.7	42.9	-8.1	62.3	58.5	-6.2

It can be seen from Table 2 that female ATDs are different from Nigerian female adults in both stature and body weight. The difference was large in body weight rather than stature. Small and mid size female from Hausa, Igbo and Yoruba are slightly different from ATDs in stature. Biggest difference of 16.7% is observed for Hausa female adults in body weight. Yoruba female are approximately equal to small and mid size female ADTs in stature, but the difference in body weight is however very high. Among the three ethnic groups, Igbo female was found to slightly differ from ATDs in both stature and weight with difference ranging from -2.1 to 1.6%. Hence small and mid size female ATD could represent Igbo female in vehicle crash testing because of small difference in anthropometric characteristics.

Table 3 compares percentiles points of female ATDs with their corresponding values in Nigerian female adults. The 5th nominal percentiles of small female ATD correspond to 10th and 11th percentiles of Hausa and Igbo small female respectively. However, small and midsize female Igbo are 1 and 4 percentile points lower than ATDs in body weight. Yoruba midsize female is 1 percentile point below the reference ATD in stature.

Table 3 Comparison of percentiles between ATD and male adults for three ethnic groups

ATD	Stature			Weight		
	Reference Values ATD (mm)	**Nominal percentile ATD**	**Corresponding percentile (Hausa)**	**Reference Values ATD (kg)**	**Nominal percentile ATD**	**Corresponding percentile (Hausa)**
Small Female	1513.0	5	10	46.7	5	16
Mid size Female	1618.0	50	60	62.3	50	60

	Reference Values ATD (mm)	**Nominal percentile ATD**	**Corresponding percentile (Igbo)**	**Reference Values ATD (kg)**	**Nominal percentile ATD**	**Corresponding percentile (Igbo)**
Small Female	1513.0	5	11	46.7	5	4
Mid size Female	1618.0	50	58	62.3	50	46

	Reference Values ATD (mm)	**Nominal percentile ATD**	**Corresponding percentile (Yoruba)**	**Reference Values ATD (kg)**	**Nominal percentile ATD**	**Corresponding percentile (Yoruba)**
Small Female	1513.0	5	6	46.7	5	11
Mid size Female	1618.0	50	49	62.3	50	66

DISCUSSION

The main purpose of this study is to compare the anthropometry of Nigerian female adults and ATDs. The results demonstrate that reference ATDs are different from the female adult of three Nigerian major ethnic groups. Percentage difference between ATD and Nigerian female varying from 0.5% to 2.1% is observed in stature as shown in Table 2. Large difference in body weight ranging from 1.5% to 16.7% was also found. Small female and mid size female ATD could represent Igbo female because the difference in both stature and weight is within 2%. ATD stature and weight targets differ from the Nigerian female population by less than 11 percentile points. Small ATDs that are used in the evaluation of vehicle safety performance are not truly representing Hausa and Yoruba female adults in both stature and body weight.

Injury parameters could be different for occupant of different sizes hence there is need to take in to account the occupant size in restraint system and vehicle design (Happee *et al.,* 1998). If the size of occupant is different from that of ATDs, the position of head and neck relative to the airbag and restraint system will be different from the one intended in the design. Air bag energy absorption from head and neck depends on the trigger time and position of head relative to air bag (Melvin *et al.,* 1993). Occupants that are smaller than the crash dummies were reported to have higher neck injuries due to closeness of dummy neck with seat belt (Isa *et al.,* 2016). Since Nigerian female adult is smaller than ATD, seat belt routings would be close to their neck than hybrid III dummy which lead to high neck moments and forces. Weight plays an important role in injury severities sustained by the occupant in crash because it is related to the energy absorption of airbag, seat belt and knee bolster. Large differences in weight between ATDs and Nigerian female shown in the aforementioned results (Table 2) indicate that injury mitigation systems may not provide optimum protection to Nigerian female adults. It is therefore important to consider Nigerian population in vehicle designs. New vehicles should be tested using female ATDs of Nigerian anthropometry.

Table 4 presents the difference between small female adults and ATDs for some populations of the world. U.S. female adults are close to ATDs in stature and about 7.7% higher in body weight, which reflects increase in obesity of U.S. adults. The ATDs were produced based on U.S. anthropometric data collected about three decades ago, as such small female ATD does not represent current U.S. population (Reed and Rupp 2013). Chinese and Malaysian female adults are slightly lower in stature with close values (Cao *et al.,* 2015; Isa *et al.,* 2016). It is clear that there is a mismatch between female ATD and two most populated countries in the world (China and U.S.) especially in the body weight. It is interesting to note that among all the populations compared, Igbo small female was closer to small female ATD in stature and body weight. In summary, current ATDs may not sufficiently represent U.S., Malaysia, China and Nigerian Hausa and Yoruba female.

Table 4 Percentage difference between ATDs and adults population for some countries

Population	Difference between small size female and ATD in Stature (%)	Difference between small size female and ATD in body weight (%)
U.S. (Reed and Rupp 2013)	-0.3	7.7
China (Cao *et al.,* 2015)	-1.9	-10.1
Malaysia (Isa *et al.,* 2016)	-2.2	-12.2
Nigeria Hausa (current study)	-1.6	-16.7
Nigeria Igbo (current study)	-2.1	1.5
Nigeria Yoruba(current study)	-0.5	-8.1

Small sample size is used in the current study as compared to studies of China and Malaysia who employed data from their national database which is not currently available in Nigeria. For further improvement on this work it is therefore recommended that a standardized Nigerian anthropometric database be established in the future to enable research on automotive safety to be conducted. Also the effect of anthropometric data on injury outcome during crash should be studied. This work is important considering the new vehicles being assembled and sold in Nigeria. Crash testing using correct ATDs should become a requirement for manufacturers to sell their cars in Nigeria and Africa in general.

CONCLUSION

This work proved that Nigerian female adults from three major ethnic groups are generally different from ATDs in both stature and weight. The results indicate that current ATDs are not truly representing Nigerian female adults and this signifies differences in biomechanical response and injury level in vehicular crashes. Igbo female are very close to ATDs in weight and stature and therefore small female ATD could represent Igbo female populations. Globally however, percentage difference in body weight and stature for Igbo female was closer to ATDs than Hausa, Yoruba as well as U.S., Malaysian and Chinese adults. It is imperative therefore to put consideration into the differences in anthropometry between Nigerian female adult and ATDs in design of new vehicles used in Nigeria in order to provide effective protection against injuries to the occupants.

Conflict of Interest

The author declares that there is no conflict of interests regarding the publication of this paper.

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