# Assessing the Female Figure Identification Technique's Reliability as a Body Shape Classification System

**Abstract:**
This paper demonstrates the effects of slight differences in measurement definitions on resultant body shape classification. Ergonomic researchers consider the Female Figure Identification Technique (FFIT) a 'gold standard' body shape classification system to describe variation in a population's 3D profile. Nevertheless, researchers use FFIT without a scientific basis or considering their ergonomic suitability. This paper rigorously evaluates FFIT, focusing on ergonomics, garment construction, and scientific research applications. Through analysing 1,679 3D Body Scans, we assess the level of agreement between the FFIT's body shape classification when measurements placed following FFIT's or SizeUK's guidance. We establish how different interpretations of FFIT's measurement placement cause the same body to be categorised into different shapes - in up to 40% of cases. FFIT omits shoulder measurements that have little relationship to body shape yet are vital in garment construction. Using FFIT with different datasets and definitions, therefore, leads to inconsistent conclusions about shape differences.

**Practitioner Summary:**
To increase the effectiveness of body shape classification, research must appraise current systems through statistics. This paper demonstrates how current body definitions are too unspecific and exclude relevant body morphology for garment construction. Our paper suggests alternative anthropometrics and demographics for inclusion in a more advanced model.

**Keywords:** Body Shape, 3D Body Scanning, Clothing fit, Measurement, Anthropometrics

**Word Count:** 6,478

## Introduction

Despite garment construction practices ignoring current body shape classifications (Faust 2014), body shape underpins how ergonomists, practitioners, and researchers understand the human form. An increasing number of clothing ergonomics academics are embracing the Female Figure Identification Technique (FFIT) developed by Simmons, Istook, and Devarajan (2004a; 2004b). In using the FFIT, clothing ergonomics academics assume its suitability for scientific research, including nationality-based body shape comparisons (Yim Lee et al. 2007; Robinet 2009), body shape based health estimations (P. Sarakon et al. 2017; 2016), and consumer's perceptions of their body's shape (Ridgway, Parsons, and Sohn 2017; Zhang et al. 2017). Body shape is also essential for online fashion retail's virtual fit/garment size prediction tools (Januszkiewicz et al. 2017). For these scientific and retail applications to be reliable, their underpinning body shape classification system must be indisputable. An indisputable system is when assessment categorises a person into the same shape every time. Consistent categorisation requires dependable definition with a system like FFIT, something which is problematic when the system and its definition need careful analysis to understand.

Given FFIT's prevalence and influence within body shape research for apparel, researchers may assume Simmons et al. (2004a; 2004b) developed a system that consistently defines body shape. The FFIT, developed using a $TC^2$ body scanner, uses six girth measurements - bust, waist, hip, high-hip, stomach, and abdomen - which is an advance on more traditional 2D width-based classifications. Width-based analysis was necessary in the FFIT development because of limitations of knowledge, but they made a clear advancement in circumferential definitions - relating shape more clearly to clothing; The FFIT then defines nine body shapes among American women (*hourglass, bottom hourglass, top hourglass, spoon, rectangle, diamond, oval, triangle,* and *inverted triangle*; see Figure 1) which is again an advance on traditional systems. The mathematical descriptors of body shapes that the FFIT proposed were based on logic: developed from literature, experts' tacit knowledge in apparel design, and visual analysis of the segmental proportions in the female body's bust-to-hips zone - excluding the shoulder-to-bust zone. However, the FFIT only provides general guidelines on how a practitioner should take its six measurements. The practitioner also needs familiarity with the $TC^2$ scanner because FFIT is grounded in the $TC^2$ scanner's software definitions. Furthermore, practitioners need careful reading of FFIT's supporting texts to ensure consistency of measurements used. Those reporting on using FFIT apply common names for measurements with multiple definitions (e.g., waist), potentially leading to significantly different measurements (Gill et al. 2014) and then different shapes.

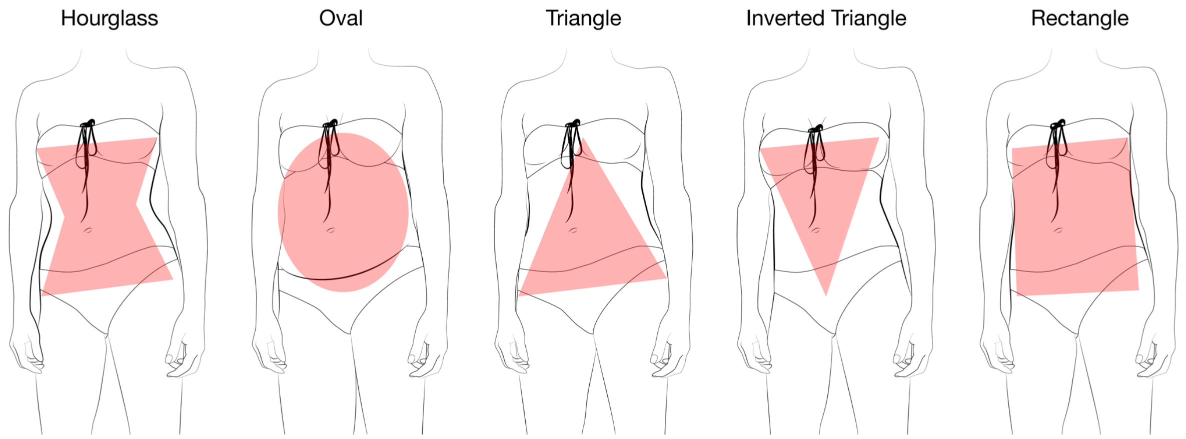


**Figure 1 Caption: Stylised examples of the Female Figure Identification Technique (FFIT) body shape classifications; based on Simmons et al. (2004a). Image based on Jones (2011).**

**Figure 1 Alt Text: Five female torsos in front-profile, with different bust, waist, and hip circumferences, visualising the body-shape differences of FFIT's five most common body shapes: Hourglass, Oval, Triangle, Inverted Triangle, and Rectangle.**

Careful analysis of FFIT shows it uses measurement definitions different from those used in significant European body scanning surveys, particularly the United Kingdom (UK) National Sizing Survey: SizeUK (2002). The SizeUK survey is the UK's first national survey of the population since the 1950s, capturing three-dimensional (3D) shapes of the population, using the same 3D body scanners ($TC^2$)

as FFIT instead of tape measures. SizeUK's goal was to support UK retailers to amend their size charts and provide a data source for scientific research, including medical, health, transport, and product design. SizeUK provides a database of anthropometric measurements for industry's use, and it not a body shape classification system. Nevertheless, Size UK influences how industry understands human measurements and their placements. Ergonomists and researchers may combine SizeUK's measurement definitions with the FFIT's body classification process. Combining measurement definitions is clear in Yim Lee et al.'s (2007) work, showing brief consideration is given to consistency of measurement definition or capture device.

The FFIT defines the hip in TC$^2$ software as the largest circumference in the crotch-to-waist region (Table 1). Size UK, in contrast, uses the buttock prominence (Seat) to define the hip. Both the FFIT and Size UK, however, use the nomenclature hip to classify their measurement. This highlights the complexities of using scanning technologies and varied measurement definitions, complicated further as some standards related to scanning ISO 20685 (2010a). The ISO Standards – 7250 (2010b) and 8559-1 (2017) – provide foundational support for research comparing measurements. Nevertheless, ISO 7250 does not have a hip circumference definition. Without a hip circumference definition, ISO 7250 has little applicability to the FFIT, and this paper, as the FFIT relies upon the hip.

While the FFIT and SizeUK use a 3D Body scanning system by TC$^2$ (2011), the lack of standardisation in methods meant three vital measurements were incompatible at the hip-girth, the waist, and the seat. Without standardisation of definition, the same tool leads to a practitioner taking a different measurement placement than the FFIT intended. SizeUK, however, uses TC$^2$'s seat measurement for its hip (see Table 1). TC²'s seat measurement corresponds to the Hip definition of International Organisation of Standardisation (ISO) 8559-1 (2017): the body's horizontal girth measured at the hip - the greatest projection at the body's back (buttocks or seat); see Figure 2.


A) Measurement Definitions: FFIT and Size UK B) Hip Level (BS ISO 8559-1:2017)

**Figure 2 Caption: Measurement Positions (A) and Hip Level under ISO 8559-1 (B)**

**Figure 2 Alt Text: Two female torsos in side-profile. Illustration A shows where FFIT and Size UK place bust, waist, and hip measurements at different levels or within different zones. In illustration A, only the bust measurement is the same in both protocols. Illustration B shows ISO 8559-1's hip level placement, which falls within the FFIT's hip zone but is higher than Size UK's hip placement.**

The FFIT's waist measurement is set as Small of the Back (SOB) +6.35 cm (FFIT), while SizeUK situates the waist as SOB +4.0 cm (SizeUK). These slight differences are problematic as the narrowing of the female form toward the rib cage can locate a much smaller circumference outside where a practitioner may designate the waist region. Altering hip and waist measurement placement significantly changes the measurements' size (Gill and Parker 2017). Suppose a practitioner uses alternative definitions of measurements within an FFIT body classification exercise. In that case, the impact of different measurement placement on body shape classification is uncertain, yet potentially damaging to the FFIT's between-studies comparisons.

The FFIT's body shape classification's applicability to extensive anthropometric surveys, including SizeUK, is potentially low yet untested. Rejecting the FFIT based on poor applicability with the anthropometric surveys that influences how industry understands human measurements is radical. Meticulous examination is, therefore, essential.

3D Body Scanning - following accepted ISO standards - takes measurements following different placement definitions than FFIT – loosely – dictates. Simmons et al. (2004a; 2004b) name the bust, waist, hip, stomach, and abdomen when developing FFIT, but omits replicable measurement definitions. Sokolowski and Bettencourt (2020, 2) even state, “Simmons et al. did not provide detailed descriptions of where on the scan these measurements were taken”. Instead, Simmons et al. (2004a; 2004b) primarily used the measurements programmed into the $TC^2$ (2011) anthropometric software – as their later work with Yim Lee (2007) describes. Unless a researcher seeking to use FFIT has the same $TC^2$ software, they must choose measurement within the stated regions, as Figure 2 shows.

The FFIT's definitions are potentially incompatible with the way 3D Body Scanning's anthropometric software defines measurements as standard. This incompatibility may have serious consequences given the FFIT's common application to 3D Body Scanning data. The FFIT used a hip measurement definition that allows the hip circumference to occur anywhere in a given zone (see Figure 2), including above the seat. Hips cannot, anatomically, occur above the seat. This may be why SizeUK used the Seat in place of the Hip. The standard 3D body scanning posture requires participants to keep their feet at least 200 mm apart: ‘standing position A’ according to ISO 20685 (2010a). 3D Body Scanners require standing position A (Figure 3) to identify crotch and thigh geometry more accurately.

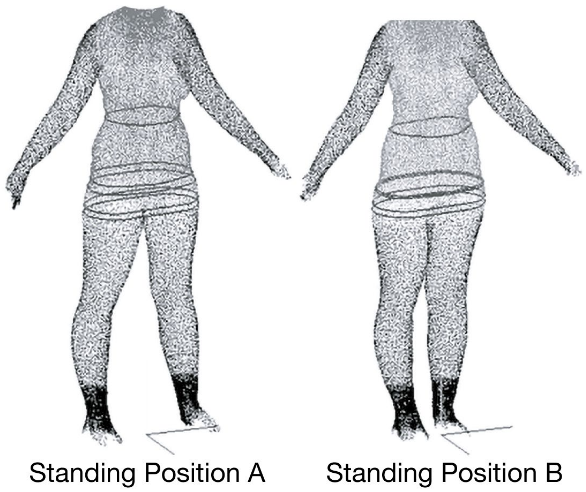


**Figure 3 Caption: Measurement Positions (A and B)**

**Figure 3 Alt Text: Two cloud-point outlines of a woman's body from a 3D Body Scanner, ISO 20685's Standing positions A (feet 200mm apart) and B (feet together).**

Nevertheless, 'standing position A' has a problem. Its wide feet position causes the largest circumference between crotch and waist to move, occurring at a position different from the hip level defined in ISO 8559-1:2017 (Gill and Parker 2017). A person's measurements, therefore, change if the practitioner uses manual or 3D Body Scanning measurement methods.

Practitioners are placing measurements on different parts of the body by using different measurement methods. If the different measurement methods can place the same body into a different shape classification, the impact may be severe. Two surveys - both using the FFIT shape classification tool but using different measurement methods - may reach conclusions about inter-group body shape differences that do not exist in reality. Researchers in these hypothetical studies may assume they classify bodies in the same way. This is because FFIT is not explicit on where to place measurements. FFIT also relies on measurements existing within zones (see Figure 2) instead of precise placements. Even the most meticulous practitioners may, therefore, be measuring bodies at different locations without knowing it.

If this is true, then the FFIT – or any research that utilises the FFIT - cannot be authoritative because of the FFIT's propensity for error caused by the effects of slight differences in measurement definitions. The published FFIT research does not, arguably, communicate the need for measurement definition standards to an adequate level. This is important because consistent results rely on practitioners applying consistent measurement definitions.

Additionally, the FFIT only classifies a person's lower-torso region instead of the entire body, despite research using the FFIT for this purpose. In defining the body, the FFIT only uses six circumferences in the region from the bust to the hip. The restricted body form consideration limits how the FFIT might inform pattern construction because it excludes measurements in the critical upper-body control zone/ the shoulders' anchor area. Unlike earlier body classification systems – e.g., Rasband (1994) – the FFIT's shape sorting formulae excludes shoulder anthropometry. Shoulder measurement's exclusion is surprising as they are essential for clothing design and construction (Aldrich 2015; Beazley and Bond 2003). The FFIT's suitability for garment construction, and apparel related purposes, is unsubstantiated.

FFIT defines the bust in line with ISO definitions. However, as Figure 2 shows, the waist and hip are defined as occurring within zones. Within these zones, measurements can fall into regions that they would not naturally occur within. For example, the hip can occur anywhere from the crotch to the waist, including above the seat. For all definitions, this can never be classified as the hip as the seat (a circumference at maximum buttock projection) should be the upper limit. Because

FFIT omits clear measurement definitions, differently defined measurements sharing the same name are likely to be applied to the published shape calculations; as with Sokolowski and Bettencourt (2020).

While the FFIT may have specific measurements, these measurements are unavailable - and unreplicable - to the broader ergonomic field (Sokolowski and Bettencourt 2020). The measurement extract is specific to TC$^2$'s Scanner software and hardware. As measurements are used interchangeably by name, two practitioners will likely use such alternative measurements – such as SizeUK – while attempting to replicate FFIT. Sokolowski and Bettencourt (2020) even modifies FFIT to address the underlying assumptions about measurement placement that cannot work on women over size 14. However, these placement assumptions are invisible to third-party practitioners who do not run studies 'hacking' the algorithm. If using alternative measurements reclassifies bodies into different shapes, then FFIT is unauthoritative outside of its original application because of unreplicable measurement definitions. In such a situation, ergonomists who attempt to use the FFIT system in their work may not, therefore, be able to compare their work to others – but they are unaware of these underlying issues.

We aim to assess the FFIT's suitability as a body classification system for scientific research and garment construction purposes, considering how slight changes in measurement definitions may affect shape classifications. We use FFIT as the case by which to explore how body shape systems may provide unreliable when used more broadly than specified systems and measurements extractions. In pursuing this aim, we consider the following hypotheses:

1. Calculating the FFIT using alternative measurement definitions causes the same human shape to be categorised as alternative body shapes,

with a low – below 50% - agreement between measurement definition groups.

2. Waist measurements decrease by a statistically significant amount - $\alpha = 0.05$ - when taken at SizeUK's region of SoB + 4.0 cm compared to the FFIT's region of SoB + 6.35 cm: with a large effect size.
3. Waist heights increase by a statistically significant amount - $\alpha = .05$ - when taken at SizeUK's region of SoB + 6.35 cm compared to the FFIT's region of SoB + 4.0 cm: with a large effect size.
4. A person's FFIT Body Shape classification can be predicted from shoulder measurements that the FFIT excludes - *Shoulder-to-Shoulder (Horizontal), Shoulder-to-Shoulder (Calliper), and Shoulder Girth (Full) – through a statistically significant regression model;* $\alpha = .05$.

In investigating our hypotheses, we analyse 1,679 UK females' FFIT shape classification - and necessary measurements - through Kappa Measure of Agreement, T-test, Multinomial Logistic Regression, and ANOVA statistical tests.

## Materials and Methods

### *Study Population*

1,679 females participated in this study, obtained through convenience sampling. We achieved this by posting flyers and adverts on social media (Facebook and Twitter), inviting members of the public to attend open scanning sessions between 2011 to 2016 in Manchester ($n = 900$), Nottingham ($n = 201$), and London ($n = 578$).

Our sampling frame required participants to be female, over 18 years old, have no physical or cognitive disabilities, and not be pregnant during data capture. These measures ensure ethical compliance and reduce the sample's independent variables. We only sampled females because the FFIT body shape classification system relates explicitly to the female body. We gained participant consent before data collection, with full prior approval of the study by Manchester Metropolitan University's ethics committee. Personal identifiable data was collected, kept separately, and de-identified within the working data set.

*Sample Size*

To achieve a power of $\pi \geq 0.8$, we calculated the minimum sample size as 1,448 participants using G*Power (Faul et al. 2020). We calculated our sample size for a one-way between-groups ANOVA with a small sample size. We used these parameters because an ANOVA has the greatest sample requirements of all our study's tests; $Effect\ Size\ f = 0.1, \alpha = 0.05, Power\ (1-\beta) = 0.8, Grps = 8$. We sampled 1,679 participants, exceeding our minimum sample size by 231 participants.

*Sample Demographics*

The study's sample were females aged 18-84 years $(M = 31.5, SD = 14.5)$ of body mass 34.0-160.3 Kg $(M = 65.3, SD = 15.0)$, and height 133.5–188.9 cm $(M = 154.6, SD = 6.6)$. Participant ethnicity was mainly White $(n = 1315)$, but also included Black $(n = 154)$, Asian $(n = 60)$, Chinese $(n = 44)$, Mixed White and Black $(n = 30)$, Other Mixed Background $(n = 28)$, Mixed White and Asian $(n = 12)$, and other/not stated $(n = 21)$. All participants were UK females.

***Data Collection Procedure***

Before participants attended scan sessions, they were provided with guidelines regarding the body scanning requirements concerning underwear, jewellery, and hair. All participants were asked to use non-padded and non-compression underwear to avoid any distortion of their natural body shape. The research ethics prohibits scanning anybody without underwear and excludes any inspection because of privacy issues. To ensure underwear, jewellery, or hair did not distort body shapes, the research team visually inspected each subjects' collected (processed) scan data. Visual inspection ensured all landmark points and measurements were in locations according to the anatomy and surface, considering measurement standards for clothing. Scan data that provided inaccurate measurements of the participant was removed.

We used $TC^2$'s KX-16 body-scanner to collect participant's body scan data, with all participants adopting the standard scanning posture as different standing postures significantly alters waist and hip placement (Gill and Parker 2017). The standard scanning posture is 'standing position A' according to ISO 20685 (2010a); see Figure 3 that aligns with Gill et al.'s (2016) scanning protocol. We used the anonymised body scan data for measurement extraction and analysis.

Table 1 displays the definitions of anthropometric measurements and parameters used in this paper. The $TC^2$ software (TC2 2015) also uses these definitions to determine measurement placement on the body.

The Small of Back (SoB) is vital in developing the $TC^2$ software's Measurement Extraction Protocol (SizeUK 2002), as the software cannot locate the waist without some points of reference (TC2 2015). The SoB is defined as the deepest point of the spinal curve at the tangential change, closer to the buttocks (Kirchdoerfer et al. 2002), differing from traditional manual landmarking. The SoB represents the starting point for waist measurements and is key to how shape would be defined and, therefore, should be fully understood. Plus numbers (e.g. + 6.35 cm) give the distance above the SoB; defining the upper limit for the region within which a scanner can find the smallest waist circumference. SizeUK allow an upper limit of +4 cm and the FFIT +6.35 cm from the SoB; see Table 1.

**Table 1. Measurement Definitions and Parameters settings in the Measurement Extraction Protocols (MEP) of TC² based on careful analysis of the definitions used in Size UK and FFIT**

| Origin | Measurements | Definition | Parameters set in body scanning System for this work |
|---|---|---|---|
| Female Figure Identification Technique *(FFIT) Study*[1,2] | *Bust Girth* | The horizontal circumference taken across the bust points at the fullest part[1] | • Min drop in back = 0 cm,<br>• Max drop in back = 0 cm |
| | *Waist Girth* | The smallest horizontal circumference between the bust and hips, starting at the small of the back and finishing 2 ½ inches (6.35 cm) above[1]. | • Starting height for centre-back point = small of back (SoB)<br>• [2]Upper limit of centre-back point height referenced to starting point = + 6.35 cm |
| | *Hip Girth* | The largest circumference parallel to the floor: between the waist and the crotch[1] | • Upper limit = Waist Height<br>• Lower limit = crotch height |
| | *High Hip Girth* | The largest circumference, parallel to the floor: between the waist and 75% of the distance above the crotch[1] | • [2]Upper limit = 100% back of waist)<br>• [2]Lower limit = 75% of the distance from crotch to back of waist. |
| *SizeUK* | *Bust Girth* | Same as FFIT bust | Same as FFIT bust |
| | *Waist Girth* | The smallest horizontal circumference between the bust and hips starting at the small of the back (SoB) and finishing 4cm above | All the same as FFIT waist except the Upper limit of centre-back point height referenced to starting point SoB = +4 cm |
| | *Hip girth (=TC² Seat)* | TC²Seat girth instead of hip, circumference parallel to the floor at the level of Maximum projection of the buttocks in body profile[3] | Default setting |
| | *High Hip Girth* | The circumference is taken parallel to the floor: at 75% of the distance between the seat and back waist | • Upper limit = 75% of the distance from seat to back waist landmarks (see waist definition)<br>• Lower limit = Seat level (see hip girth above) |
| *TC²* | *Seat* | The girth measurement parallel to the floor at the level of Maximum projection of the buttocks in body profile[3] | Default setting |
| *This work* | *Shoulder-to-Shoulder Horizontal* | Measured across the shoulder points along a nearly horizontal plane. It is angled slightly to keep from picking up points right behind the shoulder point. | Shoulder point defined on the surface of the scan at a slope of 4.5 degrees out from a vertical line up from the armpit point. |
| | *Shoulder-to-Shoulder Calliper* | Measured from one shoulder point to the other right through the body as a straight line. | Shoulder point defined on the surface of the scan at a slope of 4.5 degrees out from a vertical line up from the armpit point. |

| | | | |
|---|---|---|---|
| | *Shoulder Girth (Full)* | The full circumference around the slice of the shoulder girth | The circumference is taken horizontally through the left and right shoulder points |
| | *Shoulder Height* | The vertical distance from the floor to the slice of shoulder girth | Based on the parameters settings of shoulder girth (full) |

[1]*Simmons et al.* (2004a; 2004b)
[2]*Devarajan and Istook* (2004)
[3]*Kirchdoerfer et al.* (2002)

*Equipment Suitability*

The TC$^2$ body scanner's suitability, reliability, and validity within clothing science research has been demonstrated by multiple authors (Pandarum, Yu, and Hunter 2011; Gropper et al. 2012; Kim et al. 2015; Gill and Parker 2017). Notably, the TC$^2$ scanner provides a greater depth and volume of data than traditional methods (Loker, Ashdown, and Schoenfelder 2005; Gill 2015). As Bye, LaBat, and Delong (2006) prove, body scanning captures points, lengths, surface, shape, and volume, while tape measures – for example – only capture length.

*FFIT Shape Identification*

Out of FFIT's nine body shapes, we used Yim Lee at el.'s (2007) algorithm for FFIT's seven body shapes in our automatic shape sorting programme; see Table 2. We categorised participants into body shape using Visual Basic (Microsoft 1998); see Appendix A's Table 8 and Box 1. We selected Yim Lee et al.'s (2007) algorithm as it is the same algorithm Simmons et al. (2004a; 2004b) used in FFIT's development. We accept that our excluded shapes (diamond and oval) would be categorised into 'other' shapes because of limitations in defining the abdomen and stomach – as Yim Lee et al. (2007) accepted. Yim Lee et al. (2007) even considered another category - 'Shape not known' - to filter unclassified shapes from the extracted measurements, as we use in Table 2; see Box 1 in Appendix A.

To investigate alternative body measurement definitions' influence on the FFIT's body shape classification, we considered three sets of measurement definitions: DS1, DS2, and DS3.

Definition Set 1 (DS1) includes the bust, waist, hip, and high hip measurements, the same as the FFIT measurement definitions (Yim Lee et al. 2007; Simmons, Istook, and Devarajan 2004a; Simmons, Istook, and Devarajan 2004b).

Definition Set 2 (DS2) includes the bust, waist, and high hip measurements, the same as the FFIT definitions. The FFIT's Hip measurement definition is, however, replaced with the SizeUK Hip measurement definition with $TC^2$'s (2011) Seat Girth measurement, presented in Table 1. For DS2, only the hip's definition is different. We maintain the other three measurements to see how changing only one measurement definition in four alters the body shape classification.

Definition Set 3 (DS3) includes the bust, waist, high-hip, and seat (in place of the hip) girth measurements, the same as the SizeUK measurement definition (TC2 2015), presented in Table 1. The bust measurement and its parameter settings in the $TC^2$ Measurement Extraction Protocol (TC2 2015) are the same for the FFIT and SizeUK; see Table 1. For DS3, all measurement definitions are as per the SizeUK sizing survey.

*Waist Measurement Parameters' Selection*

This study's two waist measurement parameters are: SizeUK's SoB + 4.0 cm region (TC2 2015) and the FFIT's SoB + 6.35 cm region (Simmons, Istook, and Devarajan 2004a; Simmons, Istook, and Devarajan 2004b; Devarajan and Istook 2004).

*Shoulder Measurements' Parameters' Selection*

The three shoulder measurement parameters we used to represent shoulder anthropometrics were: shoulder-to-shoulder (horizontal), shoulder-to-shoulder (calliper), and shoulder girth (TC2 2015). We selected these three parameters to capture the shoulder's shape, allowing shoulders to relate to the other shape classification measurements.

While higher complexities of shoulder anthropometrics - such as pitch, slope length, and front-to-back depth – may associate with FFIT body shape, we focused on key measurements traditionally used in garment construction. Using traditional measurements retains consistency with the FFIT's measurements and current practice. It was essential to select measurements that - like the other FFIT dimensions - could define the shape and provide a context within current pattern cutting practices.

*Data Handling*

Manchester Metropolitan University held the study's data within a database of UK scan data following the Data Protection Act (Great Britain 1998). A practitioner - with 15 years' experience – extracted participant data from the database before inspecting all scans to ensure the data's reliability and validity. Before conducting statistical analysis - i.e. Multinomial Logistic Regression, t-tests, or ANOVA -, we followed Tabachnick and Fidell's (2007, chap. 4) procedures to check for violation of Normality, Linearity, and Homoscedasticity assumptions. We found no serious violations, allowing us to proceed with data analysis.

***Statistical Analysis***

We undertook all statistical analysis with SPSS (IBM 2017), with initial screening in Excel (Microsoft 2019). Significance for all tests was determined at the $p \leq 0.05$

level. We interpret effect sizes and power requirements in line with Cohen's (1988) widely accepted benchmarks.

*Alternative Measurement Definitions*

We used Kappa Measure of Agreements to gauge the level of agreement between the FFIT categorical classifications under DS1, DS2, and DS3 measurement definitions, investigating hypothesis 1. High agreement indicates high stability in the classification. Table 2 shows how many participants fit each of the FFIT's body shapes, according to differential measurement definitions. We selected the hourglass body as the reference shape because it was the most common in DS1: FFIT's 'standard' interpretation.

**Table 2. Body Shape Frequencies for the definition sets 1, 2, 3 (DS1, DS2, and DS3), showing total numbers of participants in each set.**

| Body Shapes | DS1 | DS2 | DS3 |
|---|---|---|---|
| *Hourglass* | 518 | 574 | 447 |
| *Rectangle* | 425 | 632 | 779 |
| *Triangle* | 22 | 22 | 54 |
| *Bottom Hourglass* | 447 | 199 | 289 |
| *Inverted Triangle* | 10 | 20 | 21 |
| *Top Hourglass* | 62 | 103 | 86 |
| *Spoon* | 194 | 129 | 2 |
| *Shape Not Known* | 1 | 0 | 1 |

*Alternative Waist Definition's Measurement Impact*

We used T-Tests to investigate the differences between alternative waist measurement definitions. T-test one – Association of Waist – investigates hypothesis 2: the difference in waist measurements taken at the SoB + 4.0 cm and SoB + 6.35 cm regions. T-test two - Association of Waist Height - investigates hypothesis 3: the difference in waist heights taken at the SoB + 4.0 cm and SoB + 6.35 cm regions.

*Shoulder Measurement's Predictive Capability*

We used Multinomial Logistic Regression to predict the FFIT body shape classification from shoulder measurements, investigating hypothesis 4. Our model's dependant variable is the FFIT body shape classification. Our factors are shoulder-to-shoulder (horizontal), shoulder-to-shoulder (calliper), and shoulder girth (full). We used Hosmer-Lemeshow tests for each pair of shoulder measurements to assess Goodness of Fit to the multinomial logistic regression's model, using the same variables.

We used ANOVA to investigate whether the FFIT's categorical variables associate with alternative shoulder measurements (scale variables). Our ANOVA tests variable is Shoulder-to-Shoulder (Horizontal), with groupings: the FFIT body shape classification. We investigate Shoulder-to-Shoulder (Horizontal) with ANOVA because it is the most potent predictor of the FFIT's body shape classification according to our multinomial logistic regression model. As multiple comparisons in post hoc analysis increase the risk of Type I errors, we apply a Bonferroni adjustment to $p = 0.007$, mitigating Type I errors' risk (Tabachnick and Fidell 2007, 270).

*Post hoc Power Analysis*

We conducted post hoc power analysis for parametric statistics - in conjunction with calculating sample size based on power calculations - to mitigate Type II errors caused by underpowered samples (Portney and Watkins. 2009). We used our statistical analysis' results - i.e. mean difference, standard deviation, and significance - with sample size as inputs for post hoc power analysis with G*Power (Faul et al. 2020). All post hoc power analysis tests showed adequate power ($\pi \geq 0.8$) under commonly accepted power guidelines (Cohen 1988; Aberson 2011).

## Results and Analysis

### *Comparison of Body Shape Classifications following the FFIT and SizeUK definitions*

Investigating hypothesis 1, a Kappa Measurement Of Agreement test revealed negligible agreement between the FFIT categorical classifications under different measurement definitions: DS1 and DS2 ($\mathrm{K}(N = 1679) = 0.369, p < 0.01$), DS1 and DS3 ($\mathrm{K}(N = 1679) = 0.410, p < 0.01$), and DS2 and DS3 ($\mathrm{K}(N = 1679) = 0.356, p < 0.01$). Table 3 presents the inter-shape agreement for DS1, DS2, and DS3. Between 21.9% and 39.6% of participants are categorised into different body shapes, measured by disagreement between measurement definitions in Table 3.

While rectangle, inverted triangle, and top hourglass show a high level of shape classification agreement under different measurement definitions, hourglass, triangle, bottom hourglass, and spoon show low shape-classification agreement; below 50% (Peat 2001, 228).

**Table 3. Kappa Measure of Agreements, Comparison of Female Figure Identification Technique (FFIT) categorical classifications under DS1, DS2, and DS3**

| Body Shapes | DS1 and DS2 | DS1 and DS3 | DS2 and DS3 | Average |
|---|---|---|---|---|
| *Hourglass* | 68.9% | 53.3% | 77.7% | 66.7% |
| *Rectangle* | 97.6% | 100% | 99.8% | 99.1% |
| *Triangle* | 45.5% | 45.5% | 100% | 63.7% |
| *Bottom Hourglass* | 44.5% | 37.6% | 84.4% | 55.5% |
| *Inverted Triangle* | 100% | 100% | 100% | 100.0% |
| *Top Hourglass* | 100% | 85.5% | 83.5% | 89.9% |
| *Spoon* | 66.0% | 1.0% | 1.6% | 22.9% |
| *Average* | 74.6% | 60.4% | 78.1% | |

Figure 4 visualises the low degree of agreement in the body shape assigned to participants by the alternative definitions. Each of Figure 4's lines correspond to a value from Table 3. Thicker lines represent higher levels of agreement, and dashed lines represent homogeneous shape agreement. A stable body classification system would be less influenced by changes in definition and more consistently categorise the same person into the same shape, showing as a symmetrical diagram. Figure 4 instead shows asymmetrical randomness: exposing how a person can be classified in up to three distinct body shapes - depending on measurement definition selection.

We, therefore, accept Hypothesis 1.

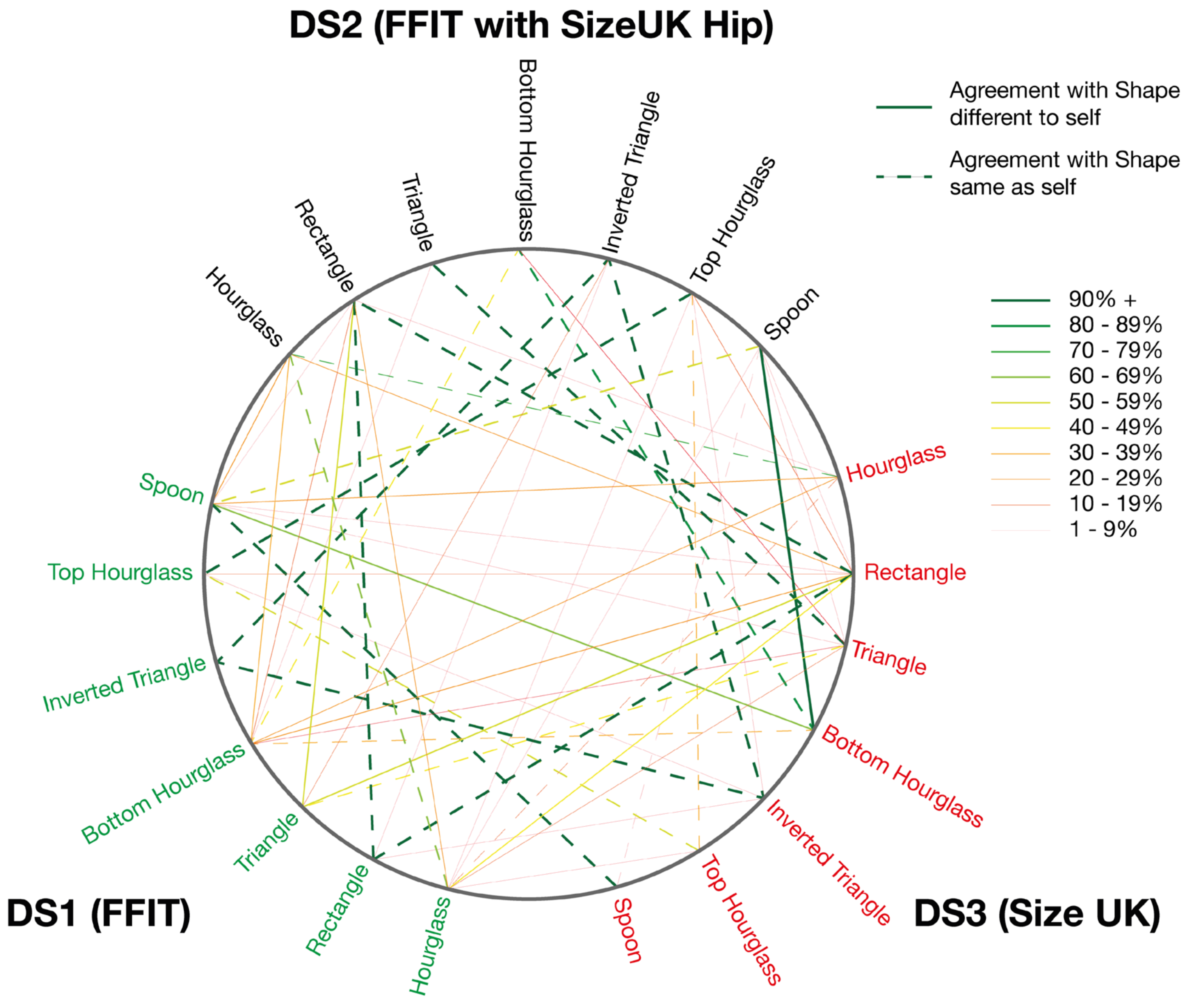


**Figure 4 Caption: Kappa Measure of Agreement between Female Figure Identification Technique (FFIT) categorical classifications under DS1, DS2, and DS3. Dashed lines agree with consistent classification across measurement sets – e.g., Rectangle with Rectangle -, thin red lines = low agreement through to thick green lines = high agreement.**

**Figure 4 Alt Text: A circle with the FFIT’s five body-shape names around the outside, repeated three times, grouped by the three sets of measurement definitions: FFIT, Size UK, and FFIT**

**with SizeUK Hip. Lines connect the names, showing only 64% to 78% of categorisations remain the same under different measurement definitions.**

**Figure 4 Long Description: A circle with the FFIT's seven body-shape names around the outside: Hourglass, Rectangle, Triangle, Bottom Hourglass, Inverted Triangle, Top Hourglass and Spoon. Each group of seven names repeats in three groups representing the three sets of measurement definitions: FFIT, Size UK, and FFIT with SizeUK Hip. Lines connect the names, showing how different measurement definitions recategorise participants into alternative body shapes. For example, 90% of women who are categorised as Bottom Hourglass under Size UK definitions are categorised as Spoon under FFIT with Size UK Hip definitions. Every body-shape name connects to every other name. Only Rectangle and Inverted Triangle have comparable – 90% - categorisation under different measurement definitions. All other body-shape categorisations recategorise participants in 20 to 50% of cases.**

### *Association of Waist Measurement Placement*

Investigating Hypothesis 2, a paired-sample t-test revealed waist measurements significantly decrease when taken within Size UK's SoB + 4.0 cm region (*M* = 79.39, *SD* = 12.64) compared to being taken within the FFIT's SoB + 6.35 cm region (FFIT) (*M* =78.13, *SD* = 12.64), $t = 32.03, p < 0.01$ (two-tailed). The t-test achieved $Power(1 - \beta\ err\ prob) = 1.0, Effect\ size\ dz = 0.8$: satisfying our statistical power requirements. The mean decrease was 1.26 cm, with a 95% confidence interval ranging from -1.33 cm to -1.18 cm. The eta-squared statistic (0.38) indicates a large effect size.

70.3% of participants had a waist circumference smaller within the FFIT's SoB + 6.35 cm region than those whose smallest waist circumference lay within SizeUK's SoB + 4.0 cm region. Waist measurements are, therefore, smaller when the 3D body scanner searched for the narrowest point within a larger waist region starting from the SoB.

We, therefore, accept Hypothesis 2.

### *Association of Waist Height*

Investigating hypothesis 3, a paired-sample t-test of the waist's height taken at the SizeUK's SoB + 4.0 cm region and the FFIT's SoB + 6.35 cm region revealed a statistically significant increase in waist location height from defining the region within SoB + 4.0 cm ($M = 104.66, SD = 5.62$) to SoB + 6.35 cm ($M = 103.44, SD = 5.58$), $t(1678) = -46.41, p < .0005$ (two-tailed). The t-test achieved $Power(1 - \beta\ err\ prob) = 1.0, Effect\ size\ dz = 1.0$, satisfying our statistical power requirements. The mean increase in waist location height was 1.22 cm, with a 95% confidence interval ranging from 1.67 cm to 1.27 cm. The eta-squared statistic (.56) indicates a large effect size. Our results show that 71.9% of participants had a higher waist height location when measured within the FFIT's SoB + 6.35 cm region. The large number of participants with their smallest waist existing above SizeUK's SoB + 4.0cm region illustrates the need to consider measurement placement and its impact on shape definitions.

We, therefore, accept Hypothesis 3.

***Shoulder Measurement's Influence***

Investigating hypothesis 4, we added shoulder measurements to a Multinomial Logistic Regression model ($\alpha = 0.05$) containing only the intercept. Adding shoulder measurements significantly improved the fit between model and data: $\chi^2(18, N = 1679) = 322.386, Nagelkerke\ R^2 = 0.18, p < 0.01$. Shoulder-to-Shoulder measurements - Horizontal and Calliper - made significant contributions to the model, as Table 4 shows. Shoulder girth (full) did not, however, significantly contribute to the model. We confirmed Horizontal and Calliper shoulder measurements' Goodness of Fit through Hosmer-Lemeshow tests for each pair of groups, with both tests reporting $p > 0.05$.

**Table 4. Predictor's unique contributions in the Multinomial Logistic Regression (N=1679)**

| Predictor | $\chi^2$ | Degrees of Freedom | *Significance (p)* |
|---|---|---|---|
| *Shoulder-to-Shoulder (Horizontal)* | 103.734 | 6 | < 0.001 |
| *Shoulder-to-Shoulder (Calliper)* | 40.047 | 6 | < 0.001 |
| *Shoulder Girth (Full)* | 5.801 | 6 | 0.446 |

Considering parameter estimates, the Horizontal and Calliper shoulder measurements' predictor has six parameters: one for each of the FFIT body shape classifications, excluding the hourglass shape that acted as the reference group. To interpret the differences between predictors, Table 5 shows the parameter estimate and lists each shoulder measurement, standardised to: $M = 0, SD = 1$.

**Table 5. Parameter Estimates Contrasting Hourglass Shape Classification versus each of the other shape classifications (N=1679)**

| Predictor | Hourglass Vs. | Coefficient (B) | Odds Ratio (OR) | Significance (p) |
|---|---|---|---|---|
| *Shoulder-to-Shoulder (Horizontal)* | Inverted Triangle | 2.152 | 8.603 | 0.004 |
| | Triangle | 1.982 | 7.258 | < 0.001 |
| | Top Hourglass | 0.999 | 2.716 | 0.009 |
| | Spoon | -0.554 | 0.575 | 0.042 |
| | Rectangle | 1.534 | 4.639 | < 0.001 |
| | Bottom Hourglass | 0.030 | 1.030 | 0.881 |
| *Shoulder-to-Shoulder (Calliper)* | Inverted Triangle | -0.859 | 0.423 | 0.266 |
| | Triangle | -1.326 | 0.265 | 0.019 |
| | Top Hourglass | 0.126 | 1.135 | 0.741 |
| | Spoon | 0.382 | 1.465 | 0.140 |
| | Rectangle | -0.932 | 0.394 | 0.367 |
| | Bottom Hourglass | -0.225 | 0.799 | 0.241 |

Shoulder-to-Shoulder (Horizontal) is the most powerful predictor for body shape classification compared to the hourglass shape. Bottom Hourglass prediction is, however, the exception.

To improve the model's predictive power, we culled Shoulder-to-Shoulder (Calliper) from the model because of its insignificant association with the FFIT Body Shape Classification. The resulting model was statistically significant $\chi^2(16, N = 1679) = 277.265, Nagelkerke\ R^2 = 0.16, p < 0.01$, correctly classifying 37.2% of all participants FFIT Body Shape. Despite the significant result, the model cannot correctly predict: Inverted Triangle, Triangle, Top Hourglass, or Spoon shapes, as Table 6 shows. Hourglass was the only shape with a high level of predictive capability: correctly identified in 63.2% of cases. Shoulder-to-Shoulder (Horizontal) may, therefore, be a further factor in defining body shape. Systems like FFIT could include this measurement.

We, therefore, reject hypothesis 4.

**Table 6. Model Prediction of Body Shape based on shoulder-to-shoulder (Horizontal) Measurements**

| | **Model Classification** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Observed** | Inverted Triangle | Triangle | Top Hourglass | Spoon | Rectangle | Bottom Hourglass | Hourglass | **Percent Correct** |
| *Inverted Triangle* | 0 | 0 | 0 | 0 | 8 | 0 | 2 | 0.0% |
| *Triangle* | 0 | 0 | 0 | 0 | 10 | 1 | 11 | 0.0% |
| *Top Hourglass* | 0 | 0 | 0 | 0 | 45 | 0 | 17 | 0.0% |
| *Spoon* | 0 | 0 | 0 | 0 | 30 | 27 | 137 | 0.0% |
| *Rectangle* | 0 | 0 | 0 | 0 | 212 | 18 | 195 | 49.9% |
| *Bottom Hourglass* | 0 | 0 | 0 | 0 | 80 | 40 | 327 | 8.9% |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Hourglass* | 0 | 0 | 0 | 0 | 108 | 38 | 372 | 71.8% |
| *Overall Percentage* | 0.0% | 0.0% | 0.0% | 0.0% | 29.4% | 7.4% | 63.2% | 37.2% |

A one-way between-groups analysis of variance explored the FFIT body shape's association with shoulder-to-shoulder (horizontal) measurements. There was a statistically significant difference at the $p < 0.05$ level for shoulder measurements for the FFIT's seven body shapes; $F(6{,}88.87) = 41.658, p < 0.01$. The eta$^2$ was 0.16, indicating a large effect size. The ANOVA test achieved $Power(1 - \beta\ err\ prob) = 1.0, Effect\ size\ f = 0.41$, satisfying our statistical power requirements. Table 7 presents the post hoc – pairwise - comparisons using the Tukey HSD test, with a Bonferroni adjustment of $p = 0.007$.

**Table 7. Post hoc (pairwise) comparisons of FFIT body shapes using Tukey HSD Test**

| **FFIT Body Shape Name** | **Spoon** $M = 36.95$ $SD = 2.82$ | **Bottom Hourglass** $M = 37.46$ $SD = 2.91$ | **Hourglass** $M = 37.81$ $SD = 2.80$ | **Triangle** $M = 39.12$ $SD = 4.01$ | **Rectangle** $M = 40.10$ $SD = 3.92$ | **Top Hourglass** $M = 41.96$ $SD = 3.83$ | **Inverted Triangle** $M = 43.69$ $SD = 3.55$ |
|---|---|---|---|---|---|---|---|
| *Bottom Hourglass* | $p = 0.514$ | | | | | | |
| *Hourglass* | $p = 0.023$ | $p = 0.606$ | | | | | |
| *Triangle* | $p = 0.042$ | $p = 0.212$ | $p = 0.501$ | | | | |
| *Rectangle* | $p < 0.001$ | $p < 0.001$ | $p < 0.001$ | $p = 0.804$ | | | |
| *Top Hourglass* | $p < 0.001$ | $p < 0.001$ | $p < 0.001$ | $p < 0.001$ | $p < 0.001$ | | |
| *Inverted Triangle* | $p < 0.001$ | $p < 0.001$ | $p < 0.001$ | $p = 0.004$ | $p = 0.009$ | $p = 0.693$ | |

Despite the ANOVA's statistically significant result, there is little difference between shoulder-to-shoulder (horizontal) and the FFIT Body Shapes. While Top

Hourglass has a significantly different shoulder measurement than every other body shape, other body shapes have at least one insignificant difference. Figure 5 visualises the confidence intervals, revealing the significant overlap between shoulder measurements and body shapes. Therefore, we cannot imply a person's shoulder-to-shoulder (horizontal) measurement with confidence from the FFIT body shape alone.

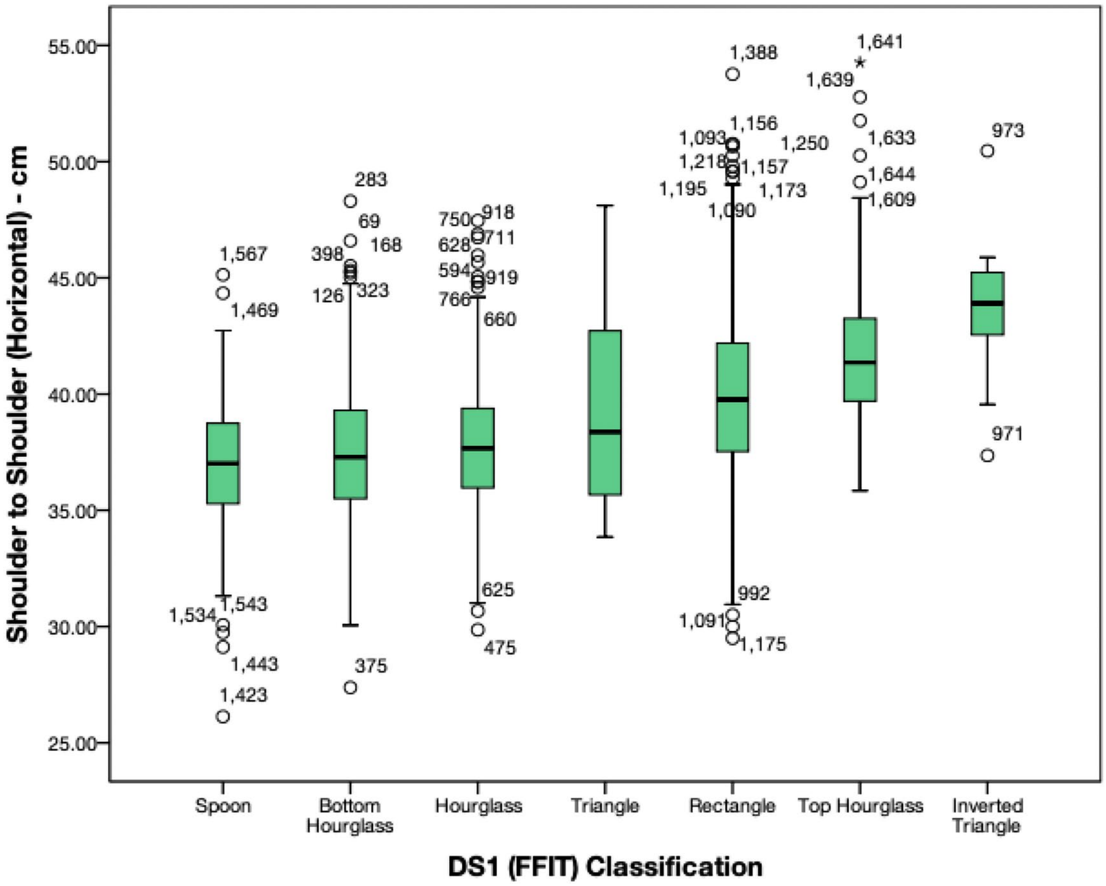


**Figure 5 Caption: A Box plot of Shoulder-Widths for Body Shape Classification**

**Figure 5 Alt Text: A Box plot showing the shoulder-to-shoulder (horizontal) measurements for FFIT's seven body shape categorisations, with Spoon, Bottom Hourglass, Hourglass, and Triangle, having overlapping distributions with an average of 37 cm. Rectangle, Top**

**Hourglass, and Inverted Triangle are significantly different from one another, with Inverted Triangle having the largest measurement at 44 cm.**

## Discussion

### *Unauthoritative Body Shape Classification*

We show that the FFIT Body shape classification system is unauthoritative because slight differences in measurement placement definition leads to different shape classifications of the same body: in up to 39.6% of cases. Something likely to occur because of variabilities in scanner definition and a lack of clarity regarding measurement definitions that hold the same nomenclature. This paper, therefore, highlights a limitation in the current body shape calculation methodologies, stemming from applying inconsistent measurement definitions in the FFIT. The results verify the FFIT may classify a single person in up to three different body shape depending on the measurement definitions associated with the named measurement. With a vague definition of body shape between sources, multiple shape interpretations occur depending on where on the body the measurement is placed, highlighted within Table 1.

Hourglass and rectangle are the dominant body shapes within our sample, as Table 3 shows. However, the shape classification transforms with the alteration in measurement definitions; see Table 3 and Figure 4. The FFIT's waist, for example, is higher in the waist region than SizeUK's waist, as defined by the SizeUK Measurement Extraction Protocol (SizeUK 2002). The mismatch in measurement definitions emphasises high specificity's importance in the way ergonomists and garment construction practitioners take measurements to extract the repeatable and accurate measurements that drive shape classification.

Significantly smaller waist measurements in the FFIT causes alternative body shape classifications. These arose when the 3D body scanner searched for the narrowest point within the FFIT's broader waist region of SoB + 6.35cm. The difficulty here is the 3D body scanner's propensity to place the waist at the ribcage's base, a measurement smaller than the actual waist. The actual waist should occur in the waist region's soft tissue (Gill et al. 2014). Furthermore, as Sokolowski and Bettencourt (2020) note, the FFIT assumes the waist region is smaller than the bust and hip. Sokolowski and Bettencourt (2020, 22) show that the FFITs categorisation – as Lee et al.'s (2007) formulate – incorrectly categorises plus-sized women "often because the waist circumferences were larger than either bust or hip".

In summary, ergonomists and garment construction practitioners require a non-equivocal and repeatable set of measurement placement definitions to produce a stable and repeatable body shape classification system. The FFIT does not adhere to this, using flawed Hip and Waist definitions that can place measurements in inappropriate regions. If the FFIT instead uses an anatomically correct Hip definition - as SizeUK's Measurement Extraction Protocol (SizeUK 2002) uses - it will raise a question about the mathematical descriptors' accuracy, presented in Table 8 in Appendix A. The mathematical descriptors were, after all, developed using information from literature, experts' tacit knowledge in apparel design and fit, and the visual analysis of segmental proportions that exist in the female body's bust-to-hips zone. Ergonomists, garment construction practitioners, and researchers cannot, therefore, consider the FFIT as accurate or appropriate enough for scientific or cultural discussion, a forum requiring non-equivocal categorisation.

***The need for shoulder Anthropometrics***

Our results show two shoulder measurements differentiate between the FFIT body shape classifications Shoulder-to-Shoulder (Horizontal) and Shoulder-to-Shoulder (Calliper). While the FFIT shapes may have an eminent power in predicting horizontal shoulder widths (see Table 5), the remaining measurements only show small to medium effect sizes. These close associations show limited power relative to the higher complexities of shoulder anthropometrics such as pitch, slope length, and front-to-back depth. Multiple interpretations of the FFIT definitions confound this, as Figure 4 outlines. Including shoulder measurements within a more advanced – future - body shape classification system may lead to more effective and stable shape outcomes that align to newer ISO standards. This outcome is expected yet previously unproven. FFIT has a limited applicability in defining more complex body morphology than 'typical' female form – as Sokolowski and Bettencourt's (2020) evolution of FFIT to include plus-sized women proves. Existing knowledge of anthropometric inter-relationships (Pheasant 1986) - and how alternative Body Shape algorithms utilise different body measurements (Johnson 1990; Sheldon 1954; Simmons, Istook, and Devarajan 2004a) - indicates the need for a study addressing body shape that is consistent. However, we show Shoulder-to-Shoulder (horizontal) measurements have a large effect size differentiating body shape classification. It is surprising that FFIT excludes the Shoulder-to-Shoulder (horizontal) measurement given its importance in industrial ergonomics and garment construction (Beazley and Bond 2003) and use systems that predate FFIT (Farr 2004; Debenhams 2014; Rasband 1994). Measurement selection is, after all, mutually exclusive to anthropometric measurement extraction technology. Through using the FFIT, ergonomists, academics, and garment construction practitioners have a deficiency in how they consider bodies.

### *Industrial Implications*

Our finding's implications are vital because clothing academics and ergonomics researchers are using the FFIT as the theoretical basis of their body shape analysis. Nevertheless, this paper proves that the FFIT's measurement definition and classification methodologies are limited as the FFIT uses Hip and Waist definitions that deviate from measurements defined in standards and in product development. The FFIT provides a foundational approach to body shape classification by key circumferences. Nevertheless, FFIT is prone to variability in application, where two practitioners can classify the same body into different shapes. We support this through replacing the FFIT's Hip definition with an anatomically correct Hip definition - as the SizeUK Measurement Extraction Protocol (SizeUK 2002) uses, producing different body shape classifications while still within the FFIT's loose measurement definitions. Practitioners' use of FFIT is not necessarily flawed if the same measurement definitions are used within comparisons – as with Lee et al. (2007). Instead, problems arise when a practitioner unknowingly uses different measurements in their work to that of the research they are comparing their results against. Nevertheless, few publications utilising FFIT provide sufficient specificity to allow practitioners to avoid such potential error. Ergonomists, academics, and garment construction practitioners must give further critical consideration to the reliability and suitability of all comparative research reliant upon body shape - especially the FFIT - within their work.

This paper shows that a person's shoulder-to-shoulder (horizontal) measurement cannot be inferred from the FFIT body shape alone. As shoulders are one of the critical measurement zones for some upper-body clothing (Beazley and Bond 2003; Aldrich 2015), FFIT cannot describe a body's form that is entirely suitable to garment selection, as with fashion retail's virtual fit/ garment size prediction tools (Januszkiewicz et al. 2017). There is, therefore, a need to develop more complex body shape identification systems that include shoulder measurement and addresses the needs for standardisation to avoid classification changes because of small discrepancies in measurement location.

## Conclusion

We set out to assess the stability of FFIT's body classification system for ergonomists, garment construction practitioners, and scientific researchers. In these fields, practitioners often classify measurements by name, meaning definitions can be challenging to ascertain. In pursuing this aim, we prove that slight differences in measurement placement definition[1] lead to different shape classifications of the same body. Because two practitioners can use two different sets of measurements sharing the same name, but with slight differences in definitions within the FFIT's tool, the FFIT body shape classification can lead to inconsistent conclusions. FFIT can reduce, or remove, this inconsistency by publishing their measurement placement definitions in a non-equivocal and replicable format.

Relating body shape to garment construction, horizontal shoulder measurements - one of the critical measurement zones for some upper-body clothing (Beazley and Bond 2003; Aldrich 2015) - only exhibits a medium association with body shape classifications. A higher level of association with the torso

[1] Small differences in measurement placement are commonplace between different studies, measurements definitions, hardware, and software.

measurements used to establish body shape by FFIT would have provided an opportunity to use the FFIT system to predict the torso's broader morphology, including the shoulder region. This indicates a need for any reliable and authoritative body classification system to include a wider variety of shoulder anthropometry.

The FFIT applied without consistent use of the same definitions is limited. Further research is needed to achieve a reliable and appropriate body classification system for scientific research or garment construction. The results provide a detailed examination of the variable approaches to defining body measurement and how these affect results. It highlights the need for researchers from all fields to work together to agree on more standardised approaches to anthropometric and ergonomic practices.

Our finding's mean clothing ergonomics academics and garment construction practitioners must question the authority of their practice that depends upon systems that have loose measurement definitions - like FFIT. They must seek to ensure measurement definitions are consistent, even when names are the same. We must, therefore, rethink and build on the last decade of progress in nationality-based body shape comparisons, body shape-based health estimations, and consumer self-perception that have drawn from the FFIT. Systems like FFIT would benefit from defining measurements by averaging over regions, reducing the influence of localised changes. Such systems could lead to more stable body shape classification systems. Researchers may have exposed between-study differences in body shape classification, but the researchers' interpretation of the FFIT's measurement placement may drive the differences, instead of genuine population body shape differences.

Ergonomics academics and garment construction practitioners need a more reliable and repeatable body classification system than currently exists. Including shoulder anthropometrics into a new body classification system should, if produced through rigorous empirical methods, create a system with direct application in clothing's development and construction processes. Then, maybe even online fashion retail's virtual try-on systems can meaningfully utilise body shape and 3D Body Scanning.

### *Limitations and Further Research*

This paper raises important questions about how ergonomists, garment construction practitioners, and researchers categorises body forms and how the field must consider body shape in the future.

While we prove that slight differences in measurement placement definition lead to different shape classifications of the same body, our investigation is limited to the FFIT and its relevant measurements. Exploring a more comprehensive range of body categorisation systems with a broader range of alternative measurement definitions will determine the generalisability of our findings outside of the FFIT.

Our research does not develop a new – more appropriate - body shape classification system. We, instead, set out clear arguments for any development in body shape classification to include unequivocal measurement definitions, apply to garment's construction practices, and include the body's additional regions aligning to contemporary ISO standards. Our work with FFIT has inspired the need for empirical investigation to define those shapes' measurements, algorithm, and classification needs. To propose a system without such rigour would be inappropriate.

Future classification systems must provide a higher degree of specificity with a lower degree of alternative interpretation for measurement location and collection compared to the FFIT. Such work must use sophisticated computational analysis that may have been unavailable to Simmons et al. (2004a; 2004b) – who used elementary logic. Our results have begun this process by showing such a new body shape classification system should include shoulder circumferences. Nevertheless, more complex additional measurements than the FFIT, and this paper, considers - such as pitch, slope length, and front-to-back depth – may lead to more appropriate body classifications for ergonomists, garment construction practitioners, and researchers to work with a higher level of precision. Other body anthropology, such as the breast, should be included as body classification has, historically, focused on the female form.

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## Disclosure Statement

The authors have no competing interests.

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# Appendix A

**Table 8. FFIT shape definitions and mathematical descriptors (Yim Lee et al. 2007; Simmons, Istook, and Devarajan 2004a; Simmons, Istook, and Devarajan 2004b)**

| # | Shapes | Measurements | Description/criteria | Mathematical descriptor (Unit in inches) | Remarks |
|---|---|---|---|---|---|
| 1 | Hourglass | Bust, waist, and hips | -If the difference in the bust and hips' circumference is minimal; AND<br>- If the ratios of bust-to-waist and hips-to waist are about equal and significant. | If (bust-hips)<1, Or<br>If (hips-bust)<3.6, Then<br>If (bust-waist)>=9 Or (hips-waist)>=10. Then Shape="Hourglass" | FFIT searches for this shape first. |
| 2 | Bottom Hourglass | Bust, waist, hips and high hips | -If the hip circumference is larger than the bust circumference; AND<br>-If the ratios of bust-to-waist and hips-to-waist are significant enough to produce a definite waistline. | If (hips-bust)>3.6 And (hips-bust)<10, Then<br>If (hips-waist)>=9, Then<br>If (high hip/waist)<1.193, Then, Shape="Bottom Hourglass" | FFIT searches for this shape before 'Triangle'. |
| 3 | Top Hourglass | Bust, waist, hips and high hips | -If bust circumference is larger than hips circumference, AND<br>-if the ratios of bust-to-waist and hips-to-waist measures are significant enough to produce a definite waistline. | If (bust-hips)>1 AND (bust-hips)<10, Then<br>If (bust-waist)>=9 Then Shape="Top Hourglass" | FFIT searches for this before 'Inverted Triangle'. |
| 4 | Spoon | Bust, waist, hips, and high hips | -If a subject has a larger circumferential difference hips and busts, AND<br>-if the bust - to - waist ratio is lower than the Hourglass shape, AND<br>-if the high hip –to- waist ratio is great | If (hips-bust)>2, Then<br>If (hips-waist)>=7, Then<br>If (high hip/waist)>1.193, Then shape ="Spoon" | |
| 5 | Rectangle | Bust, waist, and hips | -If bust and hip measurements are relatively equal, AND<br>-If bust-to-waist and hip-to-waist ratios are low | If (hips-bust) < 3.6, OR (bust-hips) <3.6 Then<br>If (bust-waist) <9 And (hips-waist) <10,<br>Then Shape = "Rectangle" | last |
| 6 | Diamond | Bust, waist, hips, stomach, and abdomen | -If the average of stomach, waist, and abdomen is more than the bust measurement | N/A | Before oval |
| 7 | Oval | Bust, waist, hips, stomach, and abdomen | -If the average of stomach, waist, and abdomen is less than the bust measurement | N/A | FFIT searches after hourglass, spoon, diamond, and bottom hourglass |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | and top hourglass |
| 8 | Triangle | Bust, waist, and hips | -If the hip circumference is larger than the bust, AND<br>- if the ratio of the hips-to-waist is small | If (hips-bust)> = 3.6 Then<br>If (hips-waist)<9 Then<br>Shape = "Triangle" | FFIT searches after Bottom Hourglass |
| 9 | Inverted Triangle | Bust, waist, and hips | -If the bust circumference is larger than hips, AND<br>-if the ratio of bust-to-waist is small | If (bust-hips)> = 3.6 Then<br>If (hips-waist)<9 Then<br>Shape = "Inverted Triangle" | FFIT searches before triangle but after hourglass |

## Box 1: Visual Basic Coding of the FFIT Formulae

```
Private Function Hourglass(Bust As Double, Hip As Double, Waist As Double) As
Boolean
    Dim BustHipResult As Boolean
    Dim HipBustResult As Boolean
    Dim BustWaistResult As Boolean
    Dim HipWaistResult As Boolean

    BustHipResult = (Bust - Hip) <= 2.5
    HipBustResult = (Hip - Bust) < 9.14
    BustWaistResult = (Bust - Waist) >= 22.86
    HipWaistResult = (Hip - Waist) >= 25.4

Hourglass = ((BustHipResult And HipBustResult) And (BustWaistResult Or
HipWaistResult))
End Function

Private Function BottomHourglass(Bust As Double, Hip As Double, HighHip As Double,
Waist As Double) As Boolean
    Dim HipBustResult As Boolean
    Dim HipWaistResult As Boolean
    Dim HighHipWaistResult As Boolean

    HipBustResult = ((Hip - Bust) >= 9.14) And ((Hip - Bust) <= 25.4)
    HipWaistResult = (Hip - Waist) >= 22.86
    HighHipWaistResult = (HighHip / Waist) < 1.193

    BottomHourglass = (HipBustResult And HipWaistResult And HighHipWaistResult)

End Function

Private Function TopHourglass(Bust As Double, Hip As Double, Waist As Double) As
Boolean
    Dim BustHipResult As Boolean
    Dim BustWaistResult As Boolean

    BustHipResult = ((Bust - Hip) > 2.54) And ((Bust - Hip) < 25.4)
    BustWaistResult = (Bust - Waist) >= 22.86
    TopHourglass = (BustHipResult And BustWaistResult)
End Function
Private Function Triangle(Bust As Double, Hip As Double, Waist As Double) As Boolean
    Dim HipBustResult As Boolean
    Dim HipWaistResult As Boolean

    HipBustResult = (Hip - Bust) >= 9.14
    HipWaistResult = (Hip - Waist) < 22.86

    Triangle = (HipBustResult And HipWaistResult)
End Function

Private Function InvertedTriangle(Bust As Double, Hip As Double, Waist As Double) As
Boolean
    Dim BustHipResult As Boolean
    Dim BustWaistResult As Boolean

    BustHipResult = (Bust - Hip) >= 9.14
    BustWaistResult = (Bust - Waist) < 22.86

    InvertedTriangle = (BustHipResult And BustWaistResult)
End Function

Private Function Rectangle(Bust As Double, Hip As Double, Waist As Double) As
Boolean
    Dim HipBustResult As Boolean
    Dim BustHipResult As Boolean
    Dim BustWaistResult As Boolean
    Dim HipWaistResult As Boolean

    HipBustResult = (Hip - Bust) < 9.14
    BustHipResult = (Bust - Hip) < 9.14
    BustWaistResult = (Bust - Waist) < 22.86
    HipWaistResult = (Hip - Waist) < 25.4

    Rectangle = (HipBustResult And BustHipResult And BustWaistResult And
HipWaistResult)
End Function

Public Function Shape_p(Bust As Double, Hip As Double, Waist As Double, Optional
HighHip As Double) As String
    Dim ResultString As String
```

```
If (Hourglass(Bust, Hip, Waist)) Then
        ResultString = "Hourglass"
    ElseIf (BottomHourglass(Bust, Hip, HighHip, Waist)) Then
        ResultString = "Bottom Hourglass"
    ElseIf (TopHourglass(Bust, Hip, Waist)) Then
        ResultString = "Top Hourglass"
    ElseIf (Spoon(Bust, Hip, Waist, HighHip)) Then
        ResultString = "Spoon"
    ElseIf (Triangle(Bust, Hip, Waist)) Then
        ResultString = "Triangle"
    ElseIf (InvertedTriangle(Bust, Hip, Waist)) Then
        ResultString = "Inverted Triangle"
    ElseIf (Rectangle(Bust, Hip, Waist)) Then
        ResultString = "Rectangle"
    Else
        ResultString = "Shape not known"
    End If
    Shape_p = ResultString
End Function


Private Function Spoon(Bust As Double, Hip As Double,
Waist As Double, HighHip As Double) As Boolean
    Dim BustHipResult As Boolean
    Dim HipWaistResult As Boolean
    Dim HighHipWaistResult As Boolean

    BustHipResult = (Hip - Bust) > 5.08
    HipWaistResult = (Hip - Waist) >= 17.78
    HighHipWaistResult = (HighHip / Waist) >= 1.193

    Spoon = (BustHipResult And HipWaistResult And
HighHipWaistResult)

End Function
```