Understanding Buttock Deformation in a Seated Posture

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Abstract

This paper presents PhD research conducted at Loughborough University in the UK, into flesh deformation of the buttocks in a seated posture. Due to a lack of detailed understanding of how the soft tissues of humans behave when in contact with a seat surface, this research aims to explore the deformation behaviour of these tissues across the sitting task. In particular the research aims to understand the relationships between the three main degrees of freedom: compression (C), anterior-posterior spread (AP), and lateral-medial spread (LM). The paper presents the analysis of C, LM and AP deformation behaviour from a study of 42 participants. Data were collected using motion capture markers attached to tight fitting clothing across one buttock of each participant via the Codamotion system. A rigid platform was used to act as a 'seat'. Participants were suspended via a hoist such that they could adopt a seated posture just short of the seat surface. Data were then captured through the sitting process from first contact to fully deformed. The resulting coordinate changes throughout this process were captured and analysed. In addition to buttock deformation data, a range of anthropometric data were captured from each participant to explore correlations between anthropometric measures and deformation behaviour to inform any later modelling activity. Findings identify clear deformation behaviour types for AP and LM spread and that participants can display predominant deformation behaviour in one axis. Typically, AP spread is greater than LM spread, and the maximum deformations occur in the lower regions of the buttocks closer to the seat surface. The development of useful models of deformation behaviour is ongoing.

Keywords: anthropometry, buttock deformation, seat design, DHM.

Introduction

The 'seated operator' is a well-known condition of human interaction with products, workplaces and environments (Li & Haslegrave, 1999). Humans adopt seated postures for a variety of tasks, and this poses particular challenges for practitioners looking to optimize the relationship between the human and their environment. As such, anthropometric databases (Dreyfuss, 1967; Gordon et al., 2014; Peebles &

Norris, 1998; Pheasant & Haslegrave, 2006) and digital human modelling systems: AnyBody, JACK, IPS-IMMA, RAMSIS, SAMMIE, Santos, amongst others, all have the capability of representing humans in a range of postures, including sitting. This provides data and tools to model and evaluate the seated human and their interactions with the world around them (Scataglini & Paul, 2019).

Seating, and the interaction with the seated human, are common areas of research (Dempster, 1955; Estrada & Vea, 2018; Quigley et al., 2001). This is partly driven by the prevalence of the seated human in everyday situations, with the majority of transport taking place with seated passengers, and many working, study, and leisure activities engaged in whilst seated. Furthermore, it is commonly understood that prolonged sitting, and / or sitting without appropriate support and / or in a 'poor' posture can lead to musculoskeletal issues (Daneshmandi et al., 2017; Picavet et al., 2016; Robb & Mansfield, 2007).

Whilst extensive research has been conducted into seating and the seated human the understanding of human-seat interactions remains a challenge, in particular soft tissue deformation experienced in the thigh-buttock region. Previous researchers have explored various methods across finite element modelling (Savonnet et al., 2018), medical imaging (Sonenblum et al., 2018), and interface pressure measurement (Oomens et al., 2003). Whilst progress in understanding has been made, variability in approaches and in the populations being studied make it difficult to draw generalisable conclusions or for broad and applicable models to be developed (Hiemstra-van Mastrigt et al., 2016).

This paper presents PhD research at Loughborough University in the UK exploring the soft tissue deformation process during sitting. The aim is to develop a model that quantifies how the human buttocks deform when contact is made with a surface. The approach taken has been to evaluate the deformation observed externally at the skin layer across the buttock and to use this to explore deformation during different stages of sitting. Ultimately models of deformation behaviour will be correlated with a range of anthropometric characteristics to provide models of deformation behaviour to inform practitioners seeking to design for this interaction.

Methods

The full description of the data collection process is documented in Harry et al., (2020), a summary is provided here. A total of 42 participants (34M-8F) were recruited from the student population. Whilst mostly a convenience sample, efforts were made to obtain a range of anthropometric variability (e.g. BMI 18.9-29.7; % Fat 4.1-38.8; hip girth 880-1250mm, waist breadth 814-1017mm; sitting height 814-1017mm). Standard ethical processes were followed. To limit variability due to external factors participants were asked to adhere to a pre-trial protocol limiting food and drink consumption, exercise etc.

A total of 31 body dimensions were collected from participants including body composition measures as well as general demographic information as shown in Table 1. Measurements were taken three times and averaged. Equipment included: digital scales (Mettler Toledo kcc150), body composition monitor (Tanita), stadiometer, anthropometer, skinfold calliper (Holtain Ltd), and measuring tape. Measurements were selected to be a combination of measures directly relevant to the buttock / thigh region (e.g. gluteal crease, hip girth), those that indicate body composition (e.g. BMI, mass, waist depth) and those that would allow categorisation against standard anthropometric data used in more general human modelling applications (e.g. stature, sitting height).

Table 1. Anthropometric data collected

General	age, mass, stature
Body Composition	% fat, fat mass, muscle mass, bone mass, BMI, physique rating
Skinfolds	pectoral, midaxillary, biceps, triceps, suprailiac, abdominal, subscapular, mid-thigh, suprapatella, medial calf, posterior-suprailiac, lumbo-sacral and gluteal crease
Girths, circumferences and others	waist girth, waist depth, waist breadth, hip girth, hip depth, hip breadth, bi-acromial breadth, buttock-knee length, knee height, sitting height, shoulder height (sitting), arm length and hand length

Data collection focused on the use of the Codamotion motion capture system that utilises infrared markers that are tracked through 3-dimensional space by tripod mounted sensor arrays. Participants all wore tight fitting leggings to which the markers were attached. The Greater Trochanter (GT) was chosen as a consistent landmark and identified by palpation and marked with a sticker or chalk pen. Using a reference template, markers were affixed horizontally from the GT around the circumference of the right buttock in 15˚ increments (labelled GT: GTmain (0), GT15, GT30, GT45, GT60, GT75). A second row of markers (GTX: main,15,30,45,60,75) were also positioned 40mm directly below the GT line as shown on the right in Figure 1. Markers were also placed on other body locations including the acromion, C7, sacrum and lateral condyle, to serve as reference locations.

To replicate a seat surface, a rigid platform was used, 700mm square in three conditions: horizontal, and two angled conditions where the rear of the seat was inclined down at 5˚ and 10˚. Note that only results from condition 1, flat seat, are presented here. Participants were suspended by a ceiling hoist via chest strap and braced against a padded knee rest to minimise sway as shown on the left in Figure 1. Participants were raised and then lowered until just at the point of contact (first contact) and held for 5-10 seconds. They were then lowered until their full weight was borne by the seat surface (fully deformed). The process was repeated 2-3 times for each participant and 3-dimensional data were sampled at 100Hz to ensure accurate readings throughout the process.

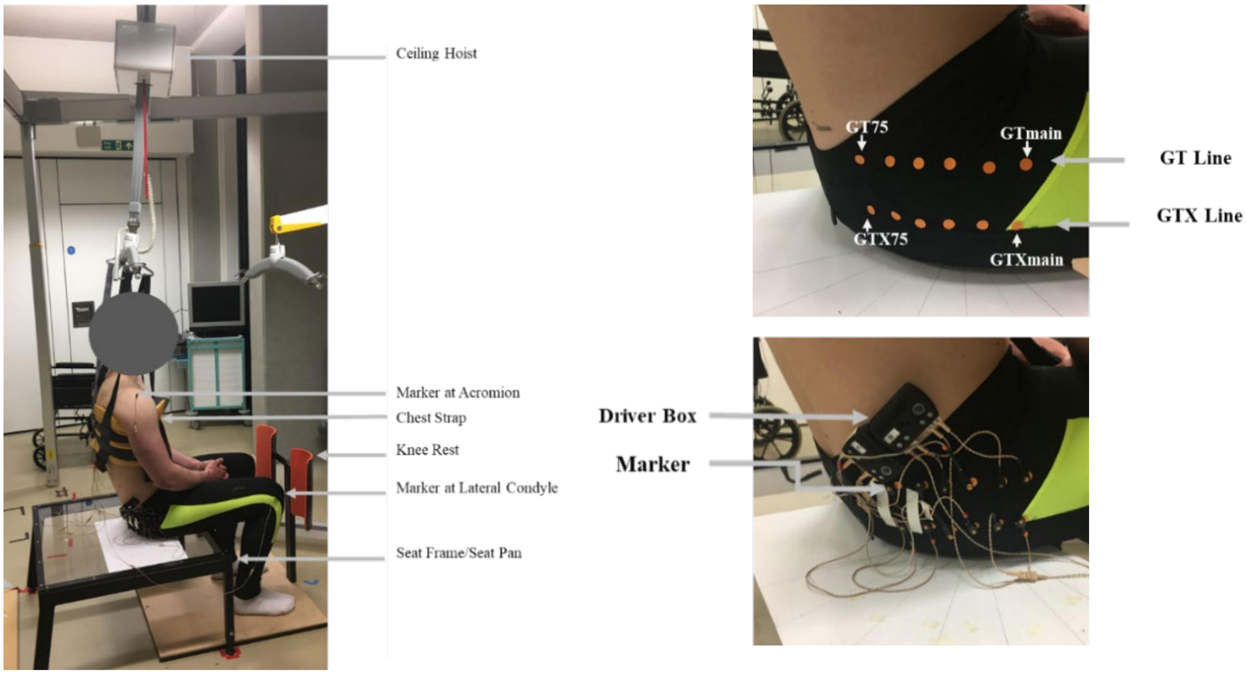


Figure 1. The experimental setup

Results

Data were captured using the Codamotion ODIN software, and then analysed using a combination of IBM SPSS, Microsoft Excel and MATLAB. Analysis focused on three core deformations: Compression (z axis), Anterior-Posterior (AP – y axis) and Lateral-Medial (LM – x axis). Throughout the analysis data were checked for consistency, missing values and outliers. A hybrid approach was taken to identifying representative deformation values. Where two good data points were available for a given marker they were averaged, where data were missing from one or more trial results were excluded.

Compression, AP Spread and LM Spread

Using MATLAB, the z-axis data for the GTmain marker was plotted per trial for all participants, as shown in Figure 2. A start and end point within 'First contact' and 'Fully Deformed' were manually identified to define a compression time domain that was then used as the frame of reference for all other markers across Compression, AP and LM spreads. As can be seen from Figure 2 the 'flat' regions defining first contact and fully deformed consist of small variations in the z value. Thus, the compression value was defined as the numerical difference between the average value taken from the first contact region and the average value taken from the fully deformed region.

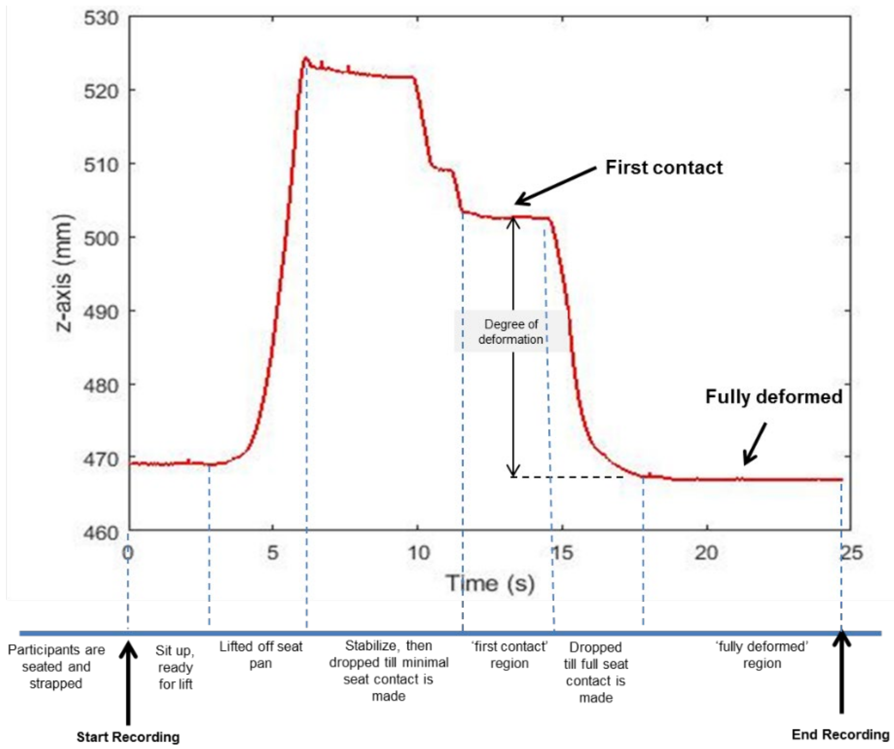


Figure 2. Exemplar results for one participant showing compression (z-axis) for GTmain

Tables 2, 3 and 4. Present the mean and standard deviations for Compression (z-axis), AP Spread (y-axis) and LM Spread (x-axis) respectively across all participants and all markers.

Table 2. / Figure 3. GT and GTX Compression values

Markers	**Mean (S.D)**		
	Trial 1	**Trial 2**	**Overall**
GTmain	33.45 (8.06)	33.75 (8.08)	33.60 (7.57)
GT15	36.48 (8.05)	37.34 (9.51)	36.91 (8.45)
GT30	41.21 (9.71)	42.19 (10.33)	41.70 (9.54)
GT45	43.37 (10.81)	44.50 (11.33)	43.96 (10.77)
GT60	43.96 (9.51)	45.87 (12.10)	44.98 (10.02)
GT75	43.19 (10.11)	44.20 (11.50)	43.70 (10.37)
GTXmain	32.23 (6.74)	33.02 (8.57)	32.81 (7.29)
GTX15	37.27 (7.22)	37.72 (9.27)	37.95 (6.98)
GTX30	41.24 (9.13)	41.60 (10.11)	41.38 (9.21)
GTX45	43.64 (9.25)	43.98 (10.37)	44.72 (8.94)
GTX60	44.36 (11.81)	46.83 (12.36)	46.01 (11.44)
GTX75	45.98 (10.33)	47.90 (11.76)	47.40 (11.12)

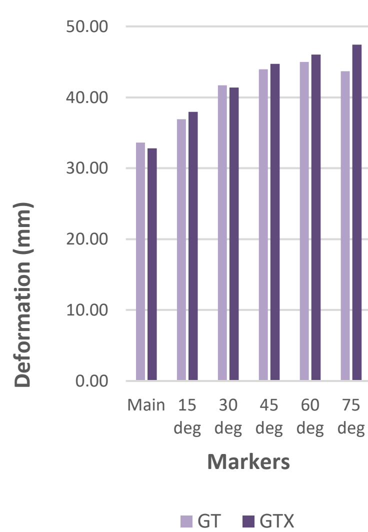


Table 3. / Figure 5. GT and GTX AP spread values

Markers	Mean (S.D)		
	Trial 1	**Trial 2**	**Overall**
GTmain	9.23 (5.48)	9.23 (6.23)	9.23 (5.59)
GT15	11.33 (5.24)	11.10 (6.14)	11.22 (5.39)
GT30	11.31 (5.27)	11.47 (6.34)	11.39 (5.54)
GT45	9.86 (6.75)	9.68 (7.58)	9.79 (6.82)
GT60	10.02 (12.35)	8.58 (8.49)	9.44 (8.74)
GT75	8.44 (8.36)	8.88 (11.80)	8.90 (9.92)
GTXmain	15.18 (15.80)	11.20 (7.31)	13.22 (9.44)
GTX15	13.94 (8.65)	11.92 (9.59)	13.35 (7.43)
GTX30	20.67 (17.54)	22.61 (20.47)	20.63 (17.95)
GTX45	25.65 (21.18)	28.13 (21.05)	25.69 (18.78)
GTX60	26.95 (24.52)	31.31 (27.01)	25.31 (21.68)
GTX75	33.83 (26.74)	35.56 (27.68)	31.19 (25.03)

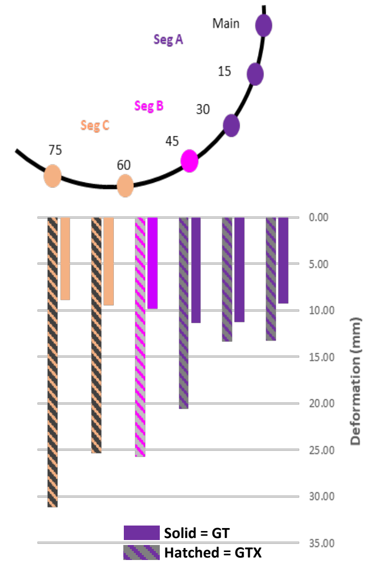
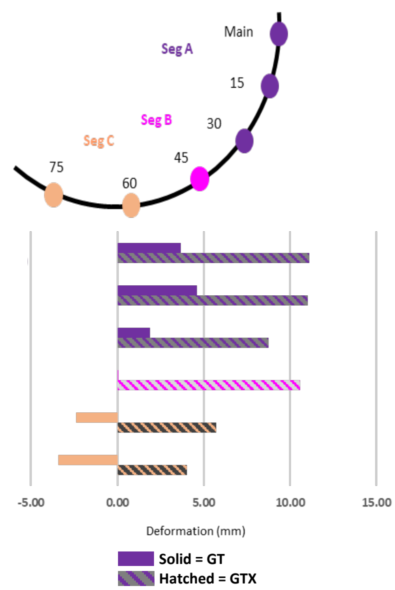


Table 4. / Figure 6. GT and GTX LM spread values

Markers	Mean (S.D)		
	Trial 1	**Trial 2**	**Overall**
GTmain	3.64 (4.11)	3.70 (4.78)	3.67 (4.32)
GT15	4.56 (5.15)	4.63 (5.38)	4.59 (5.17)
GT30	1.71 (3.73)	2.05 (4.36)	1.88 (3.90)
GT45	-0.15 (4.15)	-0.07 (4.45)	0.02 (3.97)
GT60	-2.78 (5.10)	-2.29 (4.72)	-2.37 (4.61)
GT75	-3.30 (3.76)	-3.85 (5.33)	-3.43 (3.67)
GTXmain	11.08 (5.33)	11.07 (5.21)	11.13 (5.03)
GTX15	11.20 (6.95)	10.72 (7.03)	11.02 (6.72)
GTX30	8.68 (8.73)	9.21 (9.79)	8.77 (8.96)
GTX45	9.34 (9.88)	11.62 (11.03)	10.59 (10.10)
GTX60	6.32 (8.67)	6.46 (8.84)	5.72 (8.00)
GTX75	3.18 (8.78)	5.50 (8.87)	4.05 (7.52)



In addition to statistical treatment of the deformation for each marker across the three deformation types a range of tests were performed exploring correlation within a deformation type between markers and across deformation types. Furthermore, correlations were explored to identify any relationships between deformation types and anthropometric variables. As the analysis is ongoing at this time, and for the purposes of brevity, further results will be disseminated in future publications.

Discussion

As can be seen from the results compression is the greatest magnitude of deformation for a seated human. The data highlight compression varies between 33mm and 47mm for this sample. In comparison AP deformation or front-to-back 'spread' varies between 8mm and 35mm and for LM or side-to-side spread between 0mm and -4mm and +12mm. There are various interesting observations. Firstly compression is very consistent with a steady increase from GTmain to GT75 and broadly similar levels of compression across GT and GTX suggesting deformation is relatively linear. However, for AP and LM spread deformation behaviour is much more varied. It is interesting to note that typically participants spread more to the rear than they do to the sides. Unlike compression the spread is also more pronounced closer to the seat surface (GTX) than level with the Greater Trochanter (GT). LM spread also reveals deformation behaviour that is otherwise hidden by the mean values presented here. Not all deformation observed is in the positive direction (Posterior, and Lateral). At the GT level GTmain to GT30 all spread laterally, however, GT60 and GT75 spread medially. Such behaviour is observable not only across participants but also across markers for a single participant. Due to the averaging of these results deformation for an individual can be much more variable. This highlights that the tissues of the buttocks are not only prone to spreading outwards, but also folding, in the sitting process.

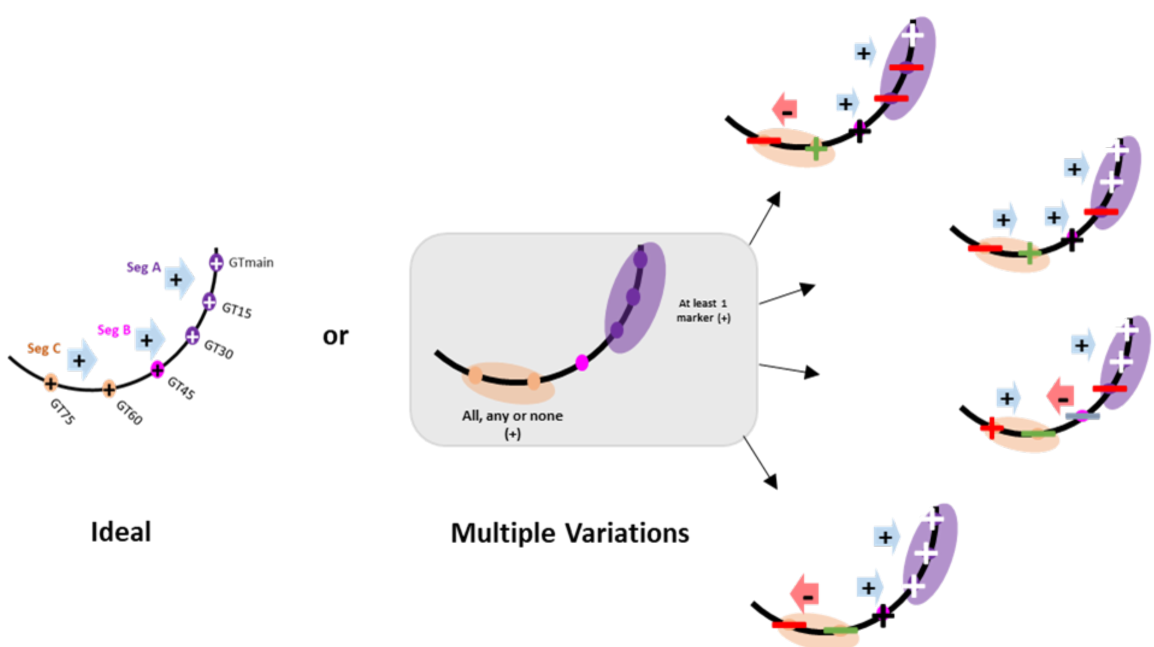


Figure 7. Exemplar LM spread types with the ideal spread shown in the left and multiple variations shown on the right.

As introduced earlier, one of the aims of this research is to quantify deformation but to also provide models for practitioners. Models are being explored investigating spread magnitude and behaviour. To assist in this process, behaviour across the buttock is examined both at the marker level and in grouped marker segments, where Segment A consists of markers to the side of the buttocks including GT(X)main to GT(X)30 and Segment C is the rear segment consisting of GT(X)60 to GT(X)75. These are separated by Segment B consisting of GT(X) 45 only. An example is shown in Figure 7. that presents an ideal Lateral spread and also many variations of Lateral spread. The intention is to explore the prevalence of spread types and provide common spread type models. These will also be combined with spread strength.

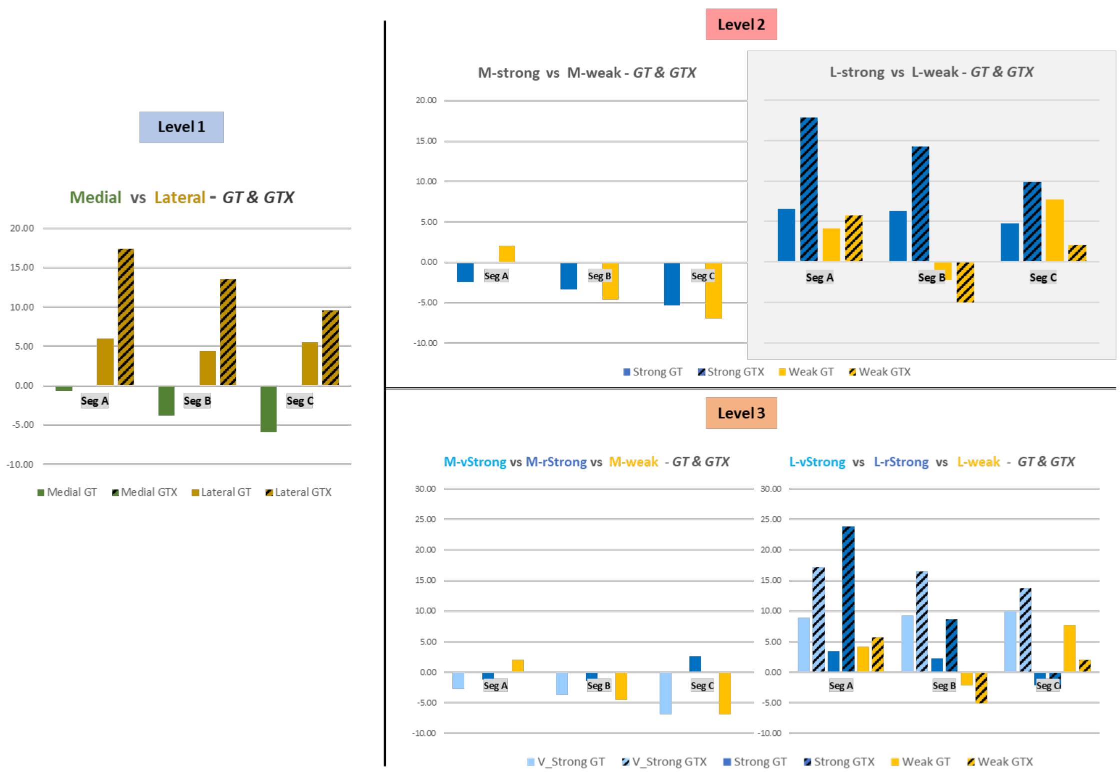


Figure 8. Exemplar LM spread strength levels

Figure 8. shows how spread varies in magnitude for each segment for both GT and GTX, across three levels of spread strength analysis ranging from Level 1 that only considers cases where participants are considered to be only Lateral or Medial spreaders, Level 2 where participants can be Strong or Weak Lateral or Medial spreaders, and Level 3 where a participant can be a very-strong, strong, or weak Lateral or Medial spreader. It is considered likely that useful spread pattern models are likely to pertain to the strongest categories of spread behaviour to inform the extremes, in a similar manner to how anthropometric models tend to rely on percentile extremes or boundary cases. However, a mapping of the full range of deformation behaviour is still useful to explore all the possible variability.

It is important to acknowledge the limitations of this research, whilst a good range of anthropometric variability is represented the sample size is ultimately limited, the data were collected with an assumption of symmetry, and the data do contain some occlusions that highlight the complexity of trying to map behaviour of human tissue that effectively becomes hidden by the very act being studied.

Conclusions

Research into buttock deformation during sitting has been presented. From a sample of 42 participants data have been collected using a motion capture system that tracks key points on the surface of the buttocks in 3-dimensions. These data provide an insight into Compression, Anterior-Posterior Spread and Lateral-Medial spread. Analysis has begun to develop models that represent the most common and most extreme spread behaviours to inform practitioners looking to understand the implications of this spread behaviour on, for example, seat design, clothing or Personal Protective Equipment. Only a sample of the research and the data have been presented here due to practical constraints. The full analysis will explore many more variables including the inclined seat surfaces, a non-rigid seat and also the correlations between deformation behaviour and anthropometric measures. Here the aim is to be able to provide predictor models such that a human with a particular BMI and waist measurement, for example, is likely to be a given type of 'spreader'.

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