A methodology to obtain anthropometric measurements from 4D scans

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Abstract

Anthropometric data can be measured manually, through traditional methods, or obtained from a 3D body scan. In both cases, anthropometric dimensions are measured in a static posture (e.g. standing, sitting) however, people interact with products and environments in movement. Anthropometry applied to the ergonomic design of spaces (e.g. workplace, cockpits) includes measurements of reaches and considers dynamic anthropometry, that is the functional ranges of movements of the limbs. In the case of wearables, products that are worn in contact to the body (e.g. clothing, protective gear), the variability of the shape and dimensions during the moment is crucial information to achieve a good fitting, comfort and performance.

The appearance of new 4D body scanning technology enables the generation of digital human models in movement which reproduce the actual body shape in motion. Anthropometry in movement is a new category of body metrics that can be obtained from a sequence of scans. In this paper, the variability of eight anthropometric dimensions (neck to waist length, back length, arm length, thigh girth, crotch length, arm girth, waist girth and hip girth) is analyzed in different movements. For this purpose, ten subjects, with a variety of morphotypes, have been measured performing different movements using a 4D scanning system. The methodology to process the sequence of body scans is described to obtain automatically anatomical references of the anthropometric measurements along the movement. The results presented show the evolution of the eight anthropometric dimensions during the movement for the different subjects and movements. The mean ranges of variation are also reported and can reach values between 2-14 cm that will be relevant information for wearable design. Anthropometric dimensions in movement is a new body metric that require further research to establish new protocols, better anthropometric definitions and the creation of new datasets.

Keywords: Anthropometry, 4D body scanning, dynamic anthropometry, body scanning in motion

Introduction

One of the main applications that drives advances in anthropometry and body shape modeling is the industry of wearables, understood as a product that is worn in direct contact with the body (e.g. personal protective equipment, clothing, exoskeletons). For those fields, there is a demand of advanced technics of body measurement, such as new protocols and advanced scanners, with the aim of ensuring an appropriate fit and comfort and to optimize product performance. The use of traditional manual techniques, have been widely used to obtain heights, widths, lengths or circumferences through the definition of anatomical points in static postures described in several standards (*ISO 7250-1:2017*, 2017; ISO 8559, 1989). Also, the appearance of conventional 3D body scanners permitted new ways of capturing the shape of the body (Daanen & Ter Haar, 2013). However, the common use of this technology consisted basically of measurement extractors, and the potential was not exploited to their maximum (Ballester et al., 2014; Robinette, 2012). Several authors study new body measurements in extreme postures with the objective of achieving better fit and performance of protective and sports clothing (Braganca et al., 2016; Klepser et al., 2020b; Masaaki Mochimaru, 2010). Scanning in cycling postures for the study of aerodynamics (Garimella et al., 2019) or, scanning in driving postures as part of the design of car interiors (Reed et al., 2014).

In the field of ergonomics, there are numerous software with specific packages for ergonomic applications which uses anthropometry. The data are re-scaled according to stature or weight to build body models of different populations and morphotypes (Rajesh & Srinath, 2016; Bubb, 2019). With respect of the design of wearable products, the variability of shapes and dimensions of the body in the interaction with the devices, is an essential input to consider. However, the interaction of device-body in movement has not been solved, further study from a dynamic perspective is required.

Klepser et al., (2020a) defined the “functional measurements”, they analysed body measurements with respect to the body using a 3D body scanner. They found points of improvement in the reproducibility of the landmarks and in the limitations of the scanners. However, all the studies on the dynamic measurements have used 3D scans to capture static postures in extreme positions. The evolution of the dynamic measurements over time while the motions are performed has not yet been studied.

New 4D scanning technology is able to capture the human body surface in motion. Thus, more realistic and complex anthropometric data can be collected allowing its application in a CAD environment for simulating human-product interactions. These 4D systems provide an enormous amount of data that must be processed automatically before being applied in ergonomics.

In the present work, a 4D scanner was used to capture a sample of people performing a series of motions. Post-processing based on homologous meshes, enables the computation of body measurements over time.

The aim of this study is to create new anthropometric definitions for eight body measurements that can be computed from 3D body scans in movement. The new anthropometric definitions should consider that anatomical references (e.g. planes, axis, landmarks) vary during the movement. The new measurements have been analyzed in a limited preliminary study with subjects.

Methods

Five females with mean heights of 163±7cm, mean weights of 60±11kg, and a distribution of Body Mass Indexes (BMI) between 17 (underweight) and 27 (overweight) kg/m^2 to cover a variety morphotypes and five males with mean heights of 173±9cm, mean weights of 75±15kg, and BMI between 17 (underweight) and 33 (obesity) kg/m^2participated in the study.

Subjects were scanned in movement using MOVE4D. This scanner is composed of modules composed by a pair of IR cameras for capturing shape and an RGB camera for capturing texture. The scanning volume is of 3x2x3m with a total of 16 modules arranged in two rows. The total resolution is under 1mm with accuracies in the order of 0.1mm. An automatic template-fitting processing was applied to obtain homologous sequences of meshes with a common topology of 50 thousand vertices (Parrilla et al., 2019). The mesh is obtained from an A-Pose template and has point-to-point correspondence along the sequence of frames and across different subjects (Ballester et al., 2018)

Each subject was scanned performing four movements at the specified frequency rates: running (60 fps), vertical jump (60 fps), trunk flexion touching feet (30 fps), and a squat (30 fps). For all these sequences of movements we have obtained eight measurements. They are the distance through the back from neck to waist, the arm length from the acromion to the wrist, the thigh girth at 25%, 50% and 75% distance from the knee to the hip respectively, the total crotch length which goes from the back waist to the front waist passing through the crotch, the arm girth, the waist girth and the hip girth. So far, measurements are taken in a static A-Pose with little postural variation across subjects (Ballester et al., 2014; Trieb et al., 2013). And are defined using the ISO 7250-1 (*ISO 7250-1:2017*, 2017; ISO 8559, 1989)and ISO 8559 (ISO 8559, 1989) standards. This makes it possible to use planes with a normal in one of the reference axes. For example, the waist girth in a static pose is obtained by slicing the body mesh with a plane at waist point with a plane perpendicular to the y axis. This procedure is not possible in dynamic poses where the waist isn't aligned with the y axis. For example, the torso could be abducted to one side or tilted front or back, and using a plane perpendicular to the y axis would give undesirable results. Table 1 includes the strategies used for the definition of the selected measurements and Figure 1 shows the measurements over the A-Pose of two users together with the points used for the calculi. In general, lengths obtained over the body surface can adopt the same definition for the standard A-pose and during the movement while girths should be redefined considering axis relative to the body segment.

Neck to waist length and total crotch length use the sagittal line of the human model to compute the respective measurements. This method of computing the measurements is inherently compatible with dynamic measurements because the sagittal line is well defined in any pose. Arm length measurement is computed by adding the measurement of two segments, one from the acromion to the elbow and another one from the elbow to the wrist. Each segment is computed by measuring the distance of the intersection of a plane and the human model surface from landmark to landmark. The orientation of these planes are obtained from the cross product of the vector joining the landmarks and the mean of the points' normals in the geodesic path between the landmarks. The definition of thigh girth and arm girth uses the orientation of the corresponding bone to create a perpendicular plane. Waist girth is computed in two segments that go from the left waist landmark to the right waist landmark, one segment goes through the front and the other one through the back. The orientation of the segment is computed as the plane that passes through left and right waist landmarks and a front landmark for the front segment, and similarly for the back segment. Finally, the hip girth is divided 5 segments. One for the back, and 4 segments for the front of the hip. This subdivision in the front of the hip is done so that when the legs reach the height of the hip, such as in a squat, the measurement doesn't go through the legs. All the above-mentioned measurements are computed using convex hull, except neck to waist and total crotch length.

Table 1. Definition of the anthropometric measurements.

Neck to waist length	Length of the sagittal semantic line from the neck to the waist.
Back length	Sum of sections from right acromion to seventh cervical vertebrae and from seventh cervical vertebrae to left acromion. The orientation of this segments is computed using the normals of the geodesic paths.
Arm length	Sum of section from acromion to elbow and from elbow to wrist. Orientation of the segments is computed with geodesic path point normals.
Thigh girth (25%, 50%, 75%)	Perimeter of the leg obtained at the corresponding percentage between the hip and knee joints with the orientation of the bone.
Total crotch length	Length of the sagittal semantic line from waist back to waist front passing through the crotch
Arm girth	Perimeter of the arm obtained in the midpoint of the acromion and the elbow with the orientation of the bone that goes from the shoulder to the elbow

Waist girth	Static definition: Perimeter at the height of the waist with horizontal orientation Dynamic definition: Sum of front and back section that go from left waist to right waist. The orientation of the front section is computed using the left and right waist points and a homologous point representing the front waist. The back section is analogous except it uses a homologous point representing the back waist.
Hip girth	Static definition: Perimeter at the height of the hip with horizontal orientation. Dynamic definition: Hip girth divided into segments, one for the back and 4 for the front. Orientation of the segments is computed with geodesic path point normals.

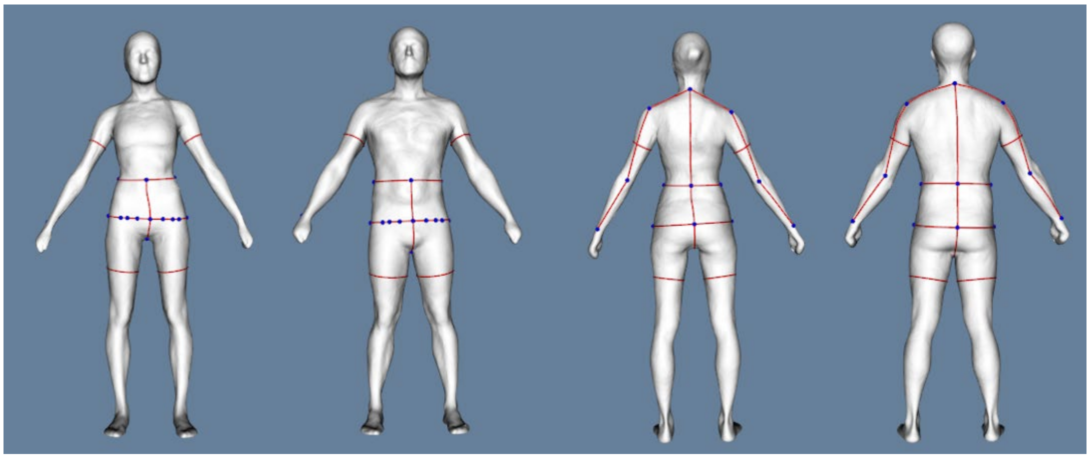
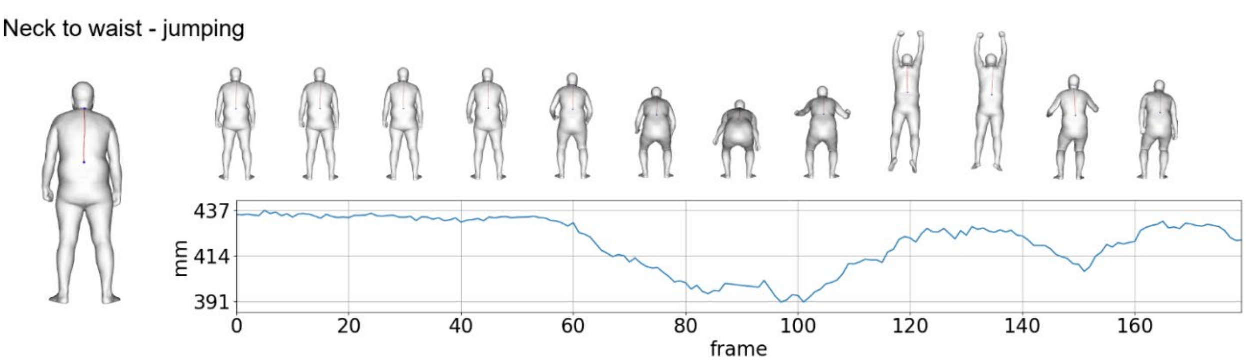


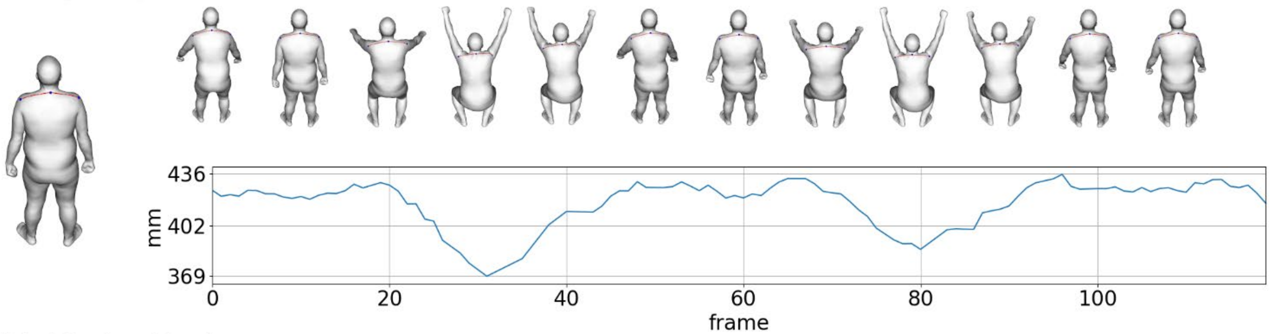
Figure 1. Surface without texture of the homologous meshes obtained with post-processing algorithms of two participants in A-Pose, front view on the left, back view on the right. Over the surface, blue points marking the points used in the definition of the 10 measurements, which appear in red.

Results

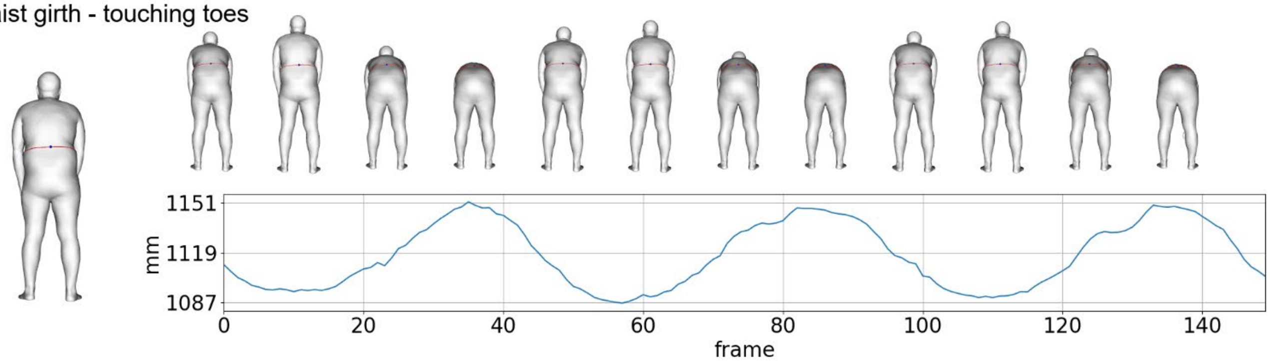
The evolution of each anthropometric measurement along the movement has been calculated in order to check if similar patterns can be observed among subjects. The patterns described by the measurements are in line of the movement. In order to illustrate this result, Figure 1 plots the measurements' evolution along the movements (frames) of a specific participant and selected motion.



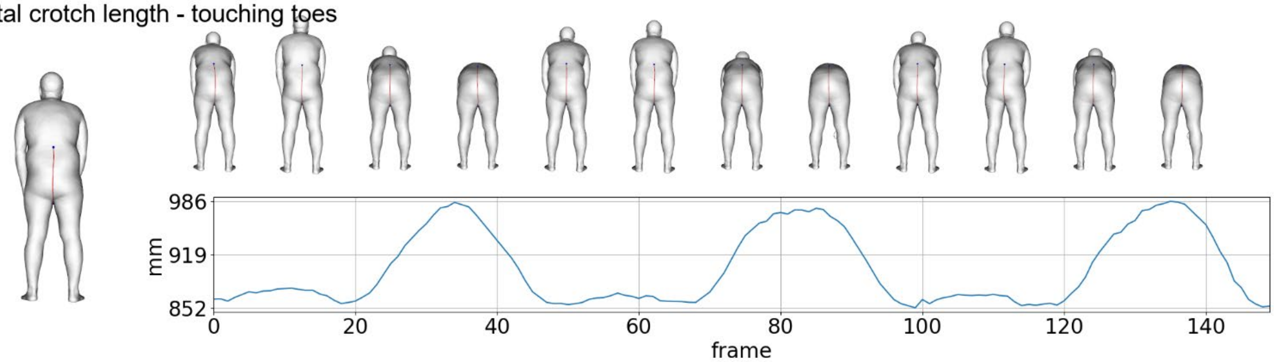
Back length - squats



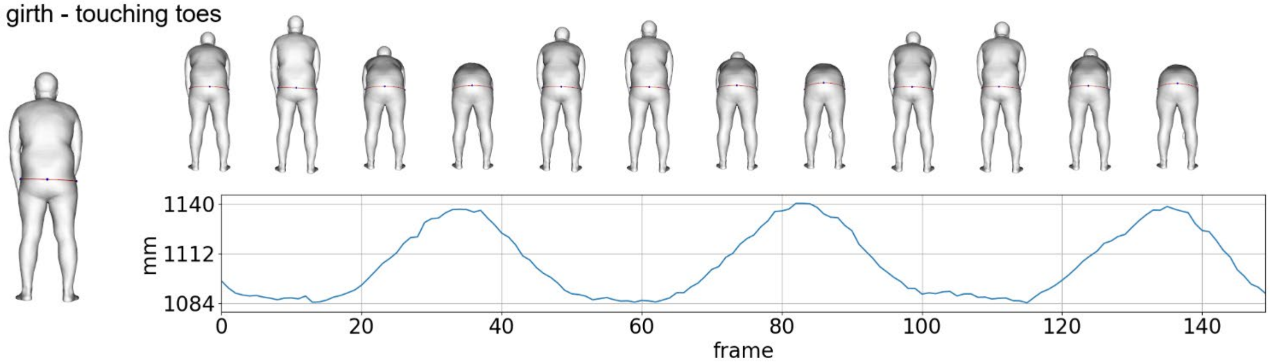
Waist girth - touching toes



Total crotch length - touching toes



Hip girth - touching toes



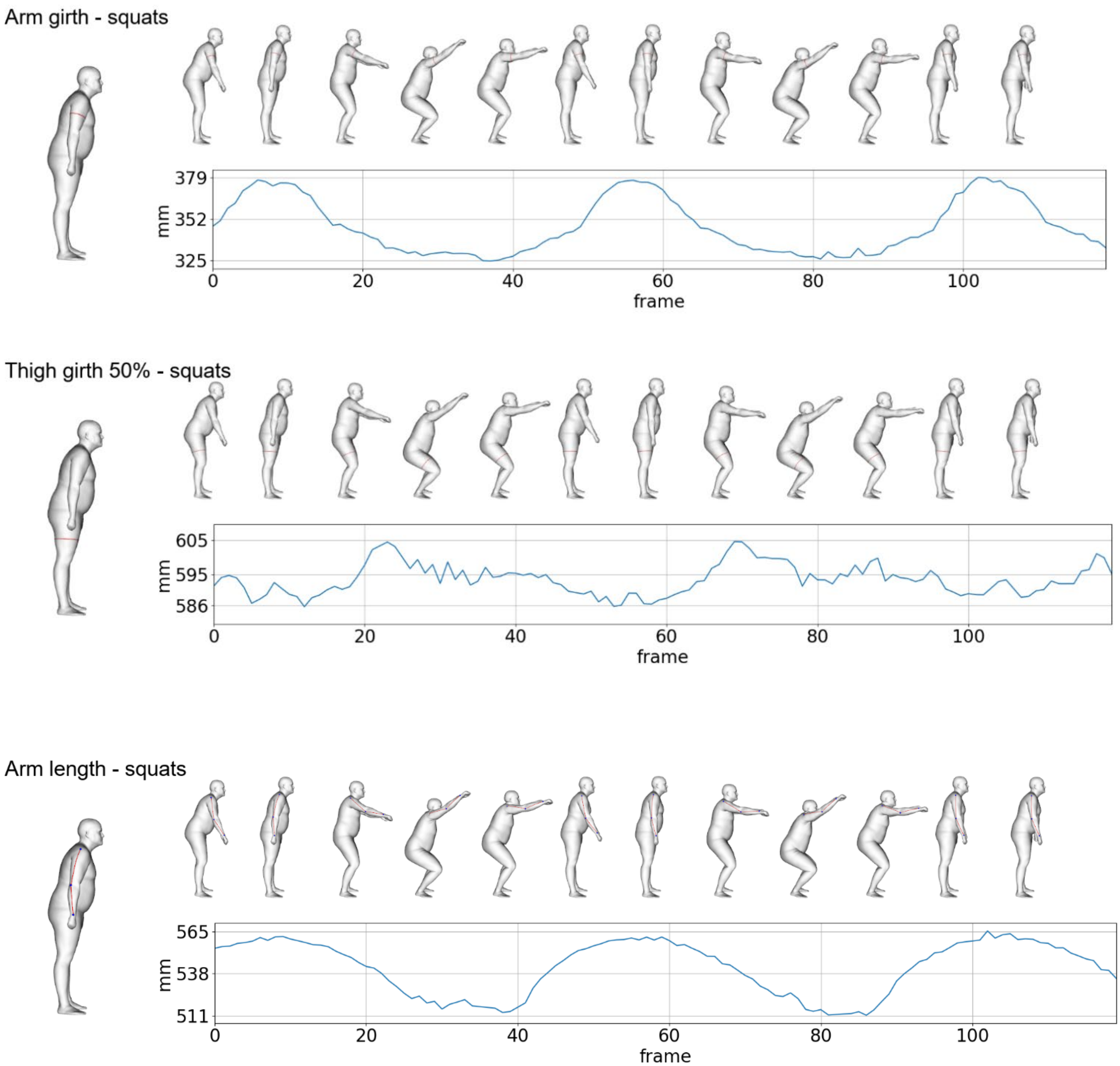


Figure 2. Plots of the measurements evolutions along the movements (frames) for one measurement and motion.

For quantifying the magnitude of the variation of each measurement throughout a motion, the range (maximum minus minimum value of length) was calculated. As an example, looking at last plot in Figure 1, the arm length of a given user varies from 511mm to 565mm while performing squats. So, the measurement's range is 54 mm, which expresses the total variation. These ranges were calculated for all motions and the mean and standard deviation of all users were obtained. In Figure 2 the plots of the four motions (running (a),jumping (b), squats (c), and touching toes (d)) mean ranges are shown.

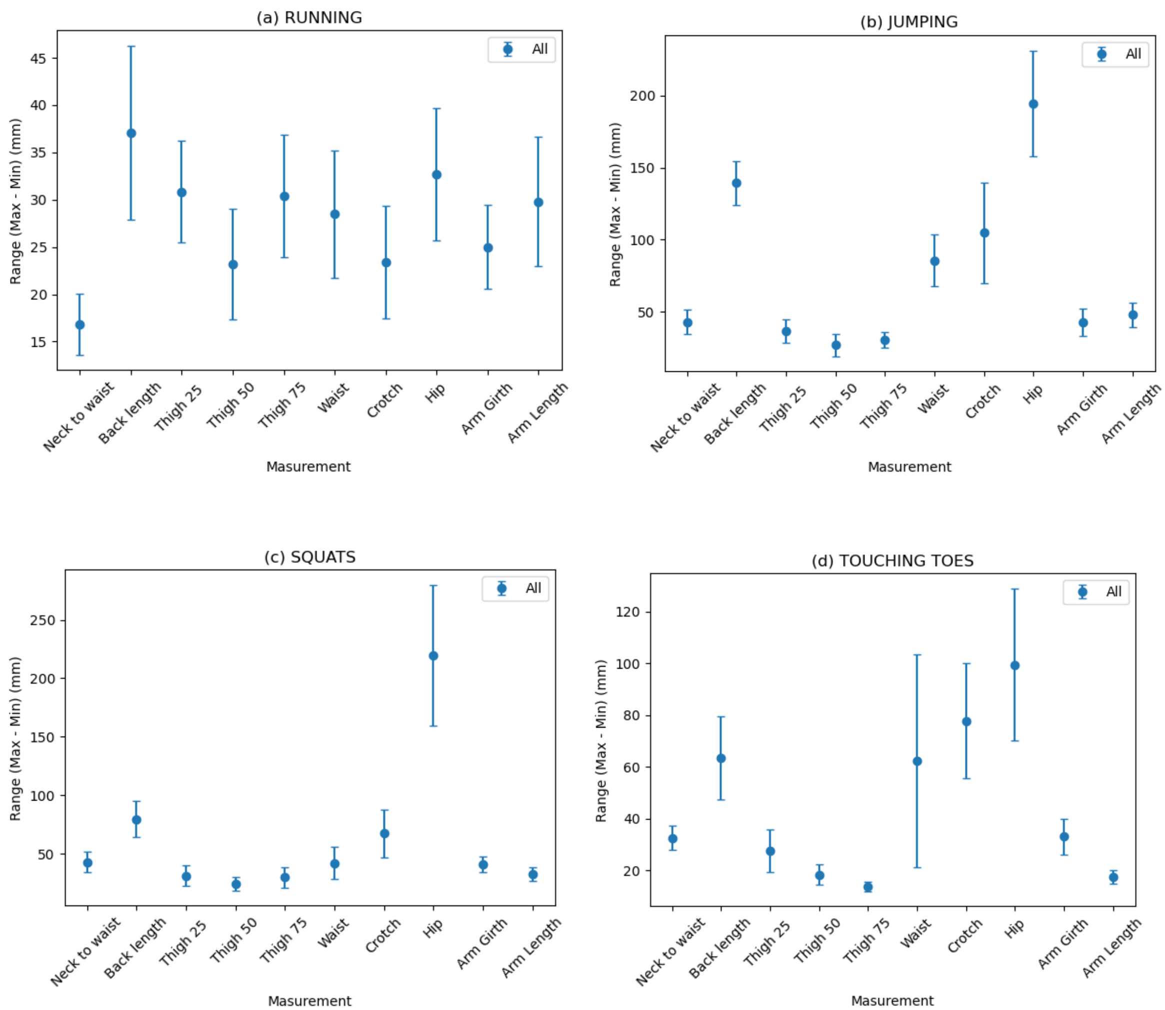


Figure 3. Mean range and standard deviations by motion: running (a), jumping (b), squats (c), and touching toes (d).

In Table 2, the mean values of ranges and their standard deviation for each motion included in Figure 2 are listed.

Table 2. Measurements mean values of ranges (maximum minus minimum) and their standard deviation by motion.

	RUNNING Mean ± St. Dev (mm)	JUMPING Mean ± St. Dev (mm)	SQUAT Mean ± St. Dev (mm)	TOUCHING TOES Mean ± St. Dev (mm)
Neck to waist	16.8 ± 3.2	42.8 ± 8.4	42.6 ± 8.7	32.5 ± 4.5
Back length	37.1 ± 9.2	139.4 ± 15.2	79.6 ± 15.4	63.4 ± 16.1
Thigh 25	30.8 ± 5.4	36.5 ± 7.9	31.1 ± 8.7	27.5 ± 8.3
Thigh 50	23.2 ± 5.8	26.7 ± 7.7	24.2 ± 5.8	18.3 ± 4.1
Thigh 75	30.4 ± 6.5	30.5 ± 5.6	29.6 ± 8.8	13.7 ± 1.8
Waist	28.5 ± 6.7	85.4 ± 17.9	41.9 ± 13.7	62.4 ± 41.2
Crotch	23.4 ± 6.0	104.8 ± 35.0	67.2 ± 20.1	77.7 ± 22.3
Hip	32.7 ± 7.0	194.5 ± 36.7	219.7 ± 60.0	99.5 ± 29.5
Arm Girth	25.0 ± 4.4	42.6 ± 9.4	41.0 ± 6.5	33.0 ± 6.9
Arm Length	29.8 ± 6.8	48.0 ± 8.5	32.4 ± 5.7	17.5 ± 2.6

Discussion and Conclusions

When observing the graphs in Figure 1 it is appreciated that in the cyclic motions, such as squat, running, and touching toes, it is clearly observable the cyclic variation in the length of the measurement. The graphs are useful to visually get an idea of the pattern and the magnitude of contraction and expansion of each measurement. In the plot neck to waist, and thigh girth in Figure 1, it can be seen that the values fluctuate from one frame to the next. This is due to the current processing methodology based on template-fitting which is calculated frame by frame. In future work, these issues will be solved by introducing a new condition that considers the neighbour frames.

The results of mean ranges (Figure 2 and Table 2) express clear variations among the four movements due to the deformation produced on each body part. The values obtained of arm and thigh girths ranges are consistent with the expected variations, and show small dispersion among users. The three thigh girths, 25, 50, and 75 ranges vary among 2 to 4 cm depending on the motion performed. In the case of the arm girth and length, the values of ranges are similar to the low extremities. The measurement of neck to waist was one of the measurements obtained without relevant discrepancies, depending on the motion. For example, when running, the ranges were smaller, being around 2 cm, while in jumping this measurement reaches a highest range around 4 cm. In the case of back length, the differences are considerably higher, conditionally to the back motion in the different exercises, vary from 4 cm when running, where no great changes are found, to 14 cm in the case of jumping.

Besides, measurements related to the trunk, such as waist girth, hip girth, and crotch length presented some noteworthy limitations. The calculation of these measurements relies on the obtaining of certain contours that depend on the rotation axes of the spinal cord, which have many degrees of freedom and change during motion. Also, some of the motions interfere in the contours, as for example, the leg raising or opening may introduce errors in the calculation of the hip girth. In conclusion, the definition of both measurements should be reconsidered. The crotch measurement also shows high ranges, from 2 cm in the case of running, to around 10 cm in the case of jumping, but no relevant problems were observed.

To compare the differences obtained with the data available in literature, only the study done by Klepser et al., (2020a) can approach the type of measurements calculated in this work. From the differences obtained the authors only “neck to hip” distance could be analogue to the present “neck to waist”. The results, for one specific subject, shows up to 14 cm of maximum range compared to 3.25 ± 0.45 cm obtained in the present study. This discrepancy can be caused but the fact that author’s measurement includes the low back part, and also, on the lack of a standard definition of the measurements in dynamic postures. Further investigation in the characterization of the deformation of the back vertical dimension is required.

Anthropometry has evolved from manual to digital measurements. Current standards based their definition of body measurements on anatomical landmarks, typically identified by palpation. The implementation of these anthropometric definitions in digital calculations from 3D body scans requires an interpretation of software developers that ends in lack of compatibility among studies. The new possibilities of computing anthropometry variation in movement capture with 4D body scanners requires additional specifications for the anthropometric definitions. Some studies are already been carried out, to investigate the validity of moving from surface markers to 4D scans (Ruescas Nicolau et al., 2022).

References related to relative axis and planes as for instance, those used in kinetic models may be a good contribution. Also, definitions that consider the possible interferences among body parts. In this context, it is relevant to advance in standardization of anthropometric definitions with a more digital perspective. Besides, measurements like the hip girth show a to high ranges and dispersion, by reason of artifacts in certain points of the movement. The occlusion of some parts of the body and the interference between parts, makes it inviable to work with a definition that was valid for static conditions. Such outcomes of the present study highlight the need of defining measurements relying on their application.

Finally, this work is presented as a first exploration in the measurement of the human body dimensions dynamically. Despite of the still existing limitations, the present methodologies open a new range of possibilities. With deeper investigation to better shaping the dynamic measurement definitions, the 4D capturing and post-processing based on homologous meshes offers new valuable data and opens a new range of possibilities in the design of wearables.

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