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Highlights:

- Video recording can be used to track trunk segment position and movement.
- This study presents a multisegmental numerical model of aligned posture in sitting.
- The use of a segmental approach gives greater detail of the trunk/spinal profile.

ABSTRACT:

Maintenance of a vertically aligned posture of the head and trunk in sitting is a fundamental skill that demonstrates the presence of neuromotor control. Clinical assessments of posture are generally subjective. Studies have quantified posture using different technologies, but the application of such technologies in a clinical environment remains difficult. Video recordings, however, are easily used clinically and have potential for quantitative analysis of movement. This study used a video-based method to generate a numerical measure of postural alignment of the head and trunk in sitting. Static and dynamic trials of 12 healthy seated adults were simultaneously recorded with a sagittal video camera and a 3D motion capture system. Segmental angles were calculated for the Head, Neck and six Trunk segments. An agreed definition of aligned static sitting posture agreed was used by five clinically experienced experts to identify video frames where the participants' posture was aligned. The five subsets of frames that defined the aligned posture were combined to give aligned segments (mean±SD) for each participant. Agreement between experts in the definition (mean) of aligned segmental angles was excellent (ICC = 0.99) and intra-assessor reliability (SD) lay within 2.1°-11.6°. Agreement between the video-based method and the 3D system was below 3.8° and 8.4° for static and dynamic trials respectively. This video-based method allowed the quantification of sitting posture and provided greater detail of the trunk/spinal profile than previous methods. It has potential as a complementary tool, alongside subjective assessments, for patients with a wide variety of pathologies.

Keywords:
Alignment; Sitting; Video; Multi-segmental model; Posture.

1. INTRODUCTION

Cerebral Palsy (CP) is a neurodevelopmental condition beginning in early childhood and persisting through the lifespan. It is characterised by a disorder of movement and posture due to non-progressive brain damage; poor motor control of the head and trunk is a common feature [1-3]. Maintenance of a vertically aligned posture of the head and trunk is fundamental to activities such as sitting or standing and requires good neuromuscular control for its achievement. Assessment of postural alignment is thus essential in order to develop an accurate therapeutic plan to target promotion of head and trunk control. During assessments, the trunk is usually considered as a single unit; however, tests such as the Segmental Assessment of Trunk Control (SATCo) [4] (used at The Movement Centre, Oswestry, UK) provides detail of control status of six trunk segments, and of free sitting if a child is able to do so. Although the SATCo has good inter- and intra-rater reliability [4], it remains a subjective assessment in common with visual and other standardised assessments of alignment [5]. Objective quantification is desirable to address the limitations of subjective assessments, to quantify changes in patients that result from therapeutic intervention, or monitor the progression of a neuromuscular condition.

Various methods of quantifying aligned sitting posture are suitable in a research environment. Translation of these methods to a clinical environment is, however, difficult. Three-dimensional (3D) motion capture systems, for example, require the markers to be constantly visible to allow the segment reconstruction. Assessment of head and trunk control in children with CP can often only be achieved with at least two people surrounding the child, especially if the child cannot sit unaided. This inevitably means that some markers are obscured thus affecting accuracy of measurement. Additionally, 3D motion capture systems are expensive with demanding data collection protocols and processing making them impractical in a clinical context. Nevertheless, they remain a ‘gold standard’ for validation of other measurement systems. The most practical clinical method has been the use of video recordings since they require minimal technical and patient preparation and can be used with all ages and severity of disability. The quantification of these video assessments is, however, essential.

This study is part of a wider investigation involving children with cerebral palsy. The aim of the study reported here was to develop a video-based method to quantify seated postural alignment of the head and trunk and to be able to identify any deviation from the aligned posture. To do this we defined the concept of alignment used to assess control, and demonstrated the accuracy of the video-based method against the gold standard for motion capture. We used a group of healthy adults for this preliminary study in order to eliminate the complications associated with compromised motor control and ensure system accuracy. The application to children with cerebral palsy provides one example of the general relevance of this concept and method.

2. METHODS

2.1. Ethics

This study was a preliminary technical component to a wider investigation involving children with cerebral palsy. Ethical approval for the complete study was obtained from the NHS Health Research Authority (NRES Committee South Central, United Kingdom) and from the University Ethics Committee. The study was conducted in accordance with the Declaration of Helsinki guidelines.

2.2. Participants

Twelve adults (6 male, 6 female, mean age 27.9±3.5 years, mean height 1.72 m ± 0.08, and weight 71.8 kg ± 11.8) were recruited to the study. All participants were healthy, did not report any fixed bony deformity or other structural problem of the spine, and had a body mass index less than 29 $kg \cdot m^{-2}$. All participants gave written informed consent for participation in this study.

All the participants wore tight fitting clothing; men were asked to leave their upper body free of clothing, women were asked to wear a customised vest that had the back removed. A clear view of the back allowed for more accurate palpation and marking of the spinous processes of the relevant vertebrae for Vicon (Vicon Nexus, Oxford Metrics, Oxford, UK) marker placement, and avoided possible artefacts generated by the movement of clothes.

2.3. Procedures

Participants sat on a bench free of back or arm support. The height of the bench was adjusted to ensure participants' feet were flat on the floor and the knees and hips were flexed at 90°. Participants were instructed that the initial trial position was with the hands in the air at shoulder height with elbows extended; a common posture used to assess trunk control in children with cerebral palsy. Data recording began before the hands were lifted to the trial position and ended when the hands were placed down again. This ensured that there were no missing data, and that only the data collected with hands in the trial position were analysed.

Participants were asked to sit upright, and verbal and manual feedback was given to achieve an initial aligned posture in sitting. Two different trials were collected, static and dynamic, to replicate physical therapy tests of control. For the static trials, participants were asked to remain still for 10 seconds in upright sitting with the hands in the trial position. For the dynamic trials, participants were asked to flex, side-flex or extend their head and trunk, returning to upright sitting after a couple of seconds and between each directional movement. This dynamic component enabled video quantification to identify deviation from the aligned posture. Lateral movements were included to represent the clinical situation more fully.

2.4. Apparatus and measurements

Data were collected simultaneously using a 3D motion capture system and one video camera recording sagittal plane movements.

3D Motion Capture

Motion data was collected using a ten-camera system (Vicon) at a frequency of 100Hz. Reflective markers were used to define eight segments (Figure 1): Head, Neck, Upper-Thoracic (UT), Mid-Thoracic (MT), Lower-Thoracic (LT), Upper-Lumbar (UL), Lower-Lumbar (LL) and Pelvis. An additional marker on the left elbow was used to identify the trial position of the arm. Marker location and segment definition were based on the description of the SATCo trunk segments [4].

Marker reconstruction and gap filling was performed using Vicon-Nexus software (version 1.8.5). Processing was performed using Visual 3D (v.5.01, C-motion, Germantown, MD, USA); a low-pass filter at 6Hz was used to filter marker trajectories, and segmental angles were calculated. A segmental angle was defined as the angle between a given segment and the absolute coordinate system and was calculated for each of the segments defined. Only the sagittal component of the segmental angles was taken into consideration. Data was exported to Matlab (Mathworks, Cambridge, MA) for further analysis.

Video recording

One video camera (JVC, HD Everio RX110) mounted on a levelled tripod was placed on the left side of the participant at a constant distance of 3.80m and constant height of 0.90m. Video was recorded at 25Hz. Small coloured blocks (2x2x2cm) were used to improve the lateral visualization and tracking of the back landmarks (Figure 1). The blocks were placed 1.5cm to the left of the equivalent reflective marker. Some of the reflective markers were also used for video tracking.

Coordinates of landmarks from video were obtained using the Dartfish marker tracking tool (Dartfish 7, TeamPro 7.0). The same operator processed all videos. Trunk segments were created using a customised Matlab code, with each segment defined as the vector joining two consecutive landmarks. Segmental angles were estimated and defined within the sagittal plane in relation to the vertical.

2.5. Data processing and analysis

The Vicon and the video signal were synchronised prior to analysis using an initial manual synchronisation followed by an automated fine-tuning using cross correlation.

For both systems, positive angles represented anterior inclination relative to the vertical, and detrended and absolute angles were calculated. The detrended angles (D) showed each angle relative to the mean angle for that trial. The absolute angles (A) for all trials were calculated relative to a single value of aligned angle defined by the participant model of alignment (see below). D angles revealed movement of segments within the trial while excluding drift in position between trials. A angles revealed position relative to the vertically aligned posture which remained true for the entire session.

Alignment model

The definition of postural alignment in sitting was consolidated in a focus group consisting of four physical therapists, each with 5 to 20 years of experience performing SATCo and using their standard working practice definition. The model of alignment was then constructed based on this agreed definition and is summarised in Figure 2. Visual identification of frames where posture was aligned was made from each of the videos. The video rating was performed independently by five clinicians with expertise in posture analysis, following the guidelines illustrated in Figure 2. The video frames where posture was identified as aligned were then used to obtain the aligned angles for each segment. For each participant, the aligned posture was defined as the set of mean ± standard deviation (SD) values for each aligned segment.

Inter-assessor reliability was tested using a two-way mixed, absolute, average measures intraclass correlation coefficient (ICC 3,1), and calculated as a collective mean SD per segment. For each assessor, intra-assessor reliability is presented as the mean SD values of the identified aligned segmental angles.

Dartfish operator reliability

Dartfish operator (DF-operator) reliability was calculated using the SD between trials. Twelve trials were processed three times with at least 36 hours between each processing and segmental angles were calculated. For each set of trials, SD was calculated as a measure of variation and the median value per segment identified. The mean value of the medians for the complete set of videos is reported in Table 1.

Video system validation

The validation of the clinically-based video method was defined as the relative agreement between the segmental angles calculated from Dartfish coordinates and the segmental angles from Vicon. Disagreement was calculated as the root mean square error (RMSE) between the signals. RMSE was calculated for D and A angles.

3. RESULTS

3.1. Alignment model

The aligned posture for each participant was quantified in Vicon and Dartfish. Inter-assessor reliability was excellent for all the segments, ICC=0.99 with 95% CI (0.99, 0.99) for both systems (Table 1). Mean SD values for the intra-assessor reliability ranged between 2.1° to 11.6°. Combining all participants, intra-assessor variation had greatest values for the Neck and smallest for the UL segment (Table 1).

Figure 3 presents the sagittal aligned mean angles and range of the Head, Neck and Trunk segments of the group of 12 healthy adults. This model is based on video data only. The combined model of the quantified aligned sitting posture of this group of adults was used as reference for the clinical video tracking and validation.

3.2. Dartfish operator reliability

DF-operator reliability varied between 0.86°±0.4 and 2.13°±0.7 for all segments. Table 1 shows little variation between segments with least reliability for the Head segment.

3.3. Clinical video tracking

Figure 4 shows a representative example of a static trial and a dynamic trial. For the static trial the variation of the angles relative to the aligned position (0°) is minimum (<1°); this matched the requirements of the trial described above. From the dynamic test it can be seen that the participant moved away from an aligned trunk posture (4-6, 8-10 and 14-16 seconds) and then returned to the initial neutral position. This confirms that video recording can be used to track trunk segments. For the Head, Neck and UT segments there was greater movement than for the LT, UL and LL, which is consistent with the anatomical characteristics.

3.4. Video system validation

Table 1 presents the numerical agreement calculated using the root mean square error (RMSE) between the Vicon and Dartfish signals. RMSE for the static trials was below 3° when using the A angles and below 0.5° for the D angles. In both cases the Head and the UT segments showed larger errors (3.76° and 3.31° for A and 1.19° and 0.74° for the D); while the Neck had low errors in both cases (1.61° and 0.37°). The RMSE for the dynamic trials was below 4° for the A and below 3° for the D angles in most cases. The Head and UT had the highest errors (8.35° and 5.9° for A and 7.9° and 5.41° for D). In contrast to the static trials, the calculation of Neck angles in the dynamic trials showed larger errors (5.5° and 5.15° for A and D respectively).

4. DISCUSSION

This study presents a video-based method to quantify aligned posture in sitting objectively. It includes the validation of this multi-segmental numerical measurement of the head and trunk against the gold standard system for motion analysis for both the maintained aligned posture (static) and for the deviation from alignment (dynamic). A numerical illustration of the aligned posture summarising all participants is presented in Figure 3.

Previous studies have quantified posture using photographs [6-8], radiographs [9-11], rastersterography [12-14] and three-dimensional (3D) motion capture systems [15-18]; most of these have value and application in research, but are rarely practical in a clinical setting. Although Curtis et al. [16] based their 3D model on the seated SATCo [4], the trunk is usually considered a single rigid segment from the iliac crests to the shoulders [17, 18], or the trunk posture is described using a general trunk angle, a cervicothoracic angle and a lumbar angle [7-11]. The calculation of separate segmental angles for the thoracic and lumbar region, as presented in this study, however, reveals detail of the spinal profile. This can be a determinant factor in the generation of a universal model of alignment as it allows the consideration of anthropometric differences.

The development of a video-based method suitable for clinical use was achieved using a video analysis system (Dartfish) and a customised code (Matlab) to track and calculate the angular displacement of the separate segments. This method has the advantage of presenting an outcome measure that is similar to the human observation of posture. Interpretation is closer to the pre-existing assessment processes used in clinical physical therapy practice. Video recorders are used commonly in clinical practice, in contrast to more complex technologies used to measure spinal angles. The videos were used to obtain angle traces that were visually equivalent to those calculated with the 3D motion capture system. Nevertheless, there were some difficulties generated by the software operation and by the inherent characteristics of the video.

Video processing required a considerable amount of manual interaction; the operator had to actively select the marker at the beginning of the trial and then manually correct the trajectory of the marker as needed. Despite reaching values of 2.13°, the DF-operator reliability was smaller than the intra-assessor reliability (Table 1). A limitation of video is that obstruction of a marker results in a compromise of marker coordinates for the duration of the obstruction. Processing of this period of marker obstruction was achieved by inferring its position based on the position of other markers and anatomical landmarks. Use of a single plane sagittal video simplifies clinical operation. This limitation implies that translations or rotations in one or both of the coronal and transverse planes, which are commonly present in clinical assessments, will result in movement artefacts which over or underestimated the displacement of a segment. This was found in the Neck and of the Head and UT segments respectively (Figure 4). For those movements performed in a true sagittal plane, however, the Dartfish tracking of the markers was close to the Vicon tracking. Clinicians should be aware of this planar anomaly but the overall value of the quantification of sagittal movement will outweigh this factor and should be addressed in future work.

The calculation of the error between Dartfish and Vicon was based on two different angle calculations, absolute (A) and detrended (D) angles. Differences between the two systems are larger for the dynamic trials than for the static trials for both A and D angles; this is associated with the plane of motion in which the movements were executed and the differentiation of movements in only the sagittal plane (automatic in Vicon but requiring visual judgement for the videos). For the static trials, the RMSE was under 1.5° for the D angles; this means that, in relation to the real fluctuations of the angles, both systems were similar irrespective of the participant's position. As a consequence, Dartfish can measure change in angle for static trials, but A angle across an entire session is less reliable (e.g. 3.76° for the Head A angle vs 1.19° for the D angle). For static and dynamic trials, the RMSE was generally smaller than the intra-assessor reliability values (Table 1).

Assessment of aligned posture is the starting point for many neuro-physical therapy strategies but, to date, could not be quantified in a clinical setting. The work presented here is an essential component for development of this complementary tool for the assessment of segmental trunk control. Furthermore, it provides validation sufficient to justify future development of an automated processing system suitable to be used in a clinical setting. A video based method has potential for use with patients with a wide variety of pathologies such as children with cerebral palsy, adult stroke or neuromuscular conditions. It does not require active patient co-operation or understanding and is suitable for use in a clinical environment. Continuous recordings of assessments can complement other clinical outcome measures and support the traditional subjective assessment of posture.

CONCLUSION

This study has demonstrated the accuracy of a video based method for objective quantification of clinically identified postural alignment of the head and trunk in sitting. These preliminary results provide a basis for future studies. This has shown to be more accurate and reliable than the subjective judgment, with the added merit of giving a numerical value. In addition, the use of a segmental approach gives the advantage of greater detail of the spinal profile. This method thus has potential as a complementary tool alongside subjective assessments for patients with a wide variety of pathologies.

CONFLICT OF INTEREST

None.

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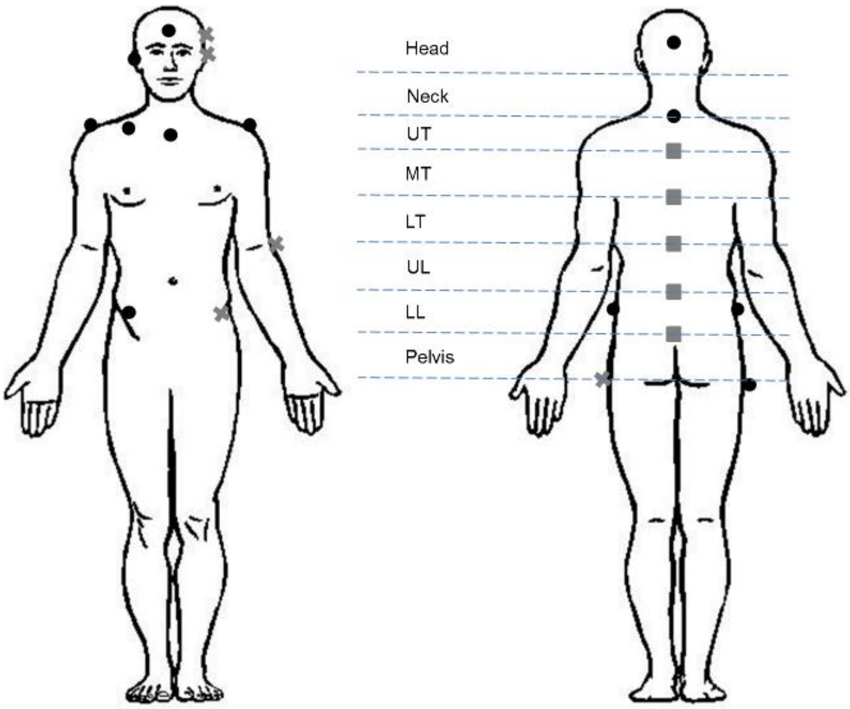


Figure 1 Marker locations and limits of trunk segments.
Dots show Vicon marker locations: forehead, occipital protuberance, right ear tragus, clavicular notch, middle of the right clavicle, acromion process of the scapula (right and left), spinous process seventh cervical vertebra (C7), iliac crest (left and right), and right anterior superior iliac spine and greater trochanter. Crosses show reflective markers used additionally for Video tracking: left ear tragus, left temporal fossa (in a vertical line from the ear tragus when the head was in neutral position), left anterior superior iliac spine and greater trochanter. Squares show reflective markers that had an equivalent coloured block: spinous process of the third, seventh and eleventh thoracic vertebrae (T3, T7 and T11), third lumbar vertebra (L3) and first sacral vertebra (S1).

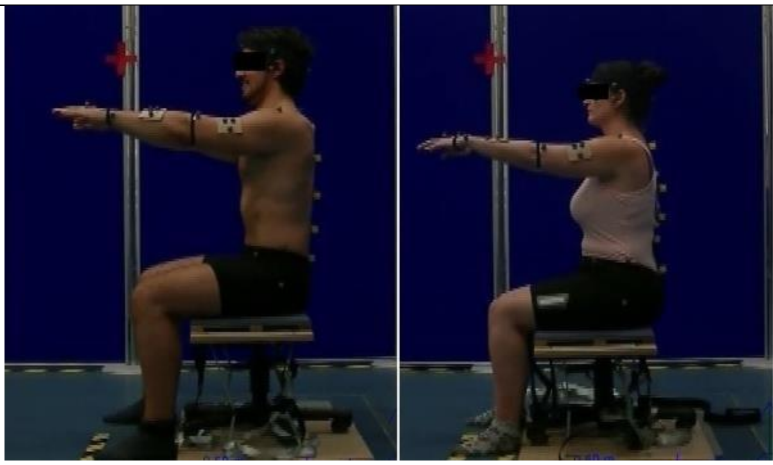
	DESCRIPTION
HEAD AND NECK	Chin: Neither protracted nor retracted
	Eyes: Looking forward
	Ear (tragus): Aligned with the hip
SHOULDER	Shoulder girdle: Neither protracted nor retracted
TRUNK	Smooth and continuous spinal curvatures Thoracic spine: Near flat as possible Lumbar spine: Slight lordosis or flat
PELVIS	Neutral
LOWER LIMBS	Hip – Knee angles: 90º - 90º
EXAMPLE	

Figure 2 Aligned static sitting posture

Qualitative description of the aligned static sitting posture agreed in the focus group and two examples of aligned posture in sitting.

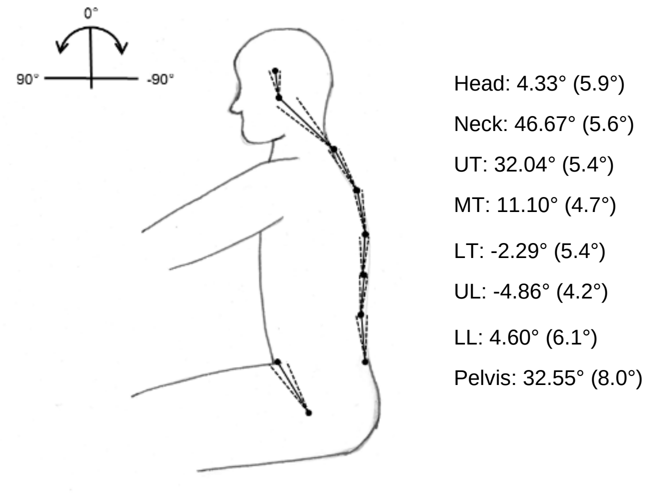


Figure 3 Representation of the aligned mean position.

Solid and dashed lines show mean and SD segment orientations respectively from all participants.

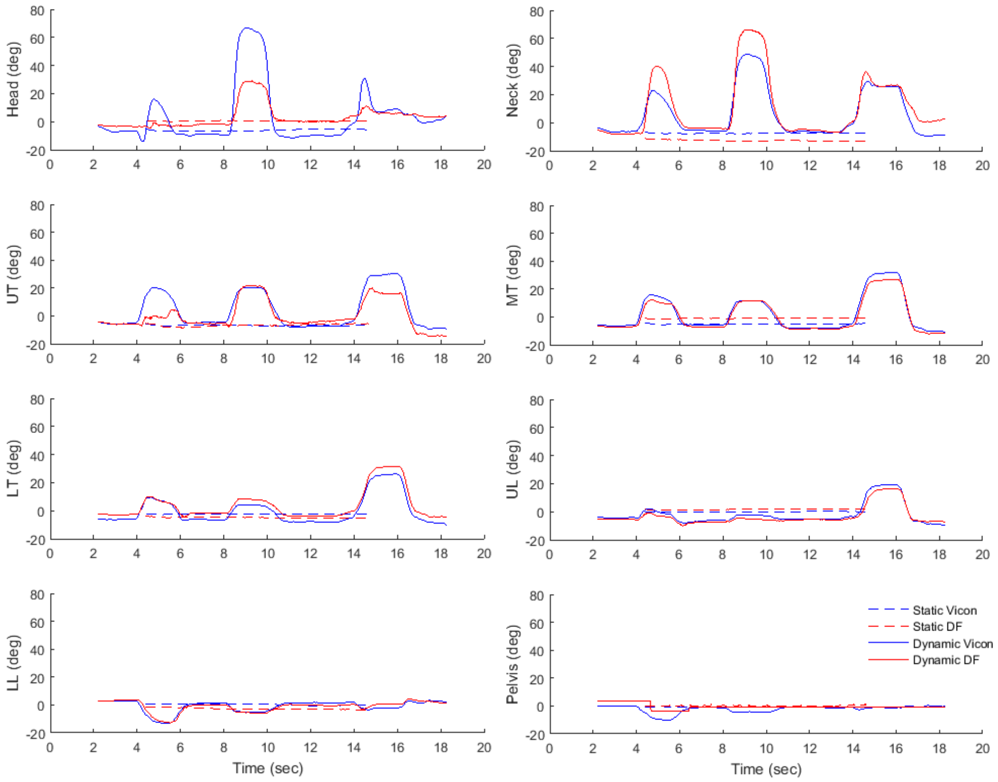


Figure 4 Representative agreement between Dartfish and Vicon.

Representative example of a time series for segmental absolute angles for a static and a dynamic trial. Dartfish angles (red) and in Vicon angles (blue) for each segment after the hands reached the trial position. The 0° position corresponds to the aligned angle per segment defined in the aligned model. A positive angle refers to flexion and a negative to extension from the aligned angle.

Table 1 Showing Dartfish operator reliability mean and SD values per segment in degrees. Inter-assessor reliability presented as ICC per segment, and as absolute values presented in degrees. The absolute values are the standard deviation of five assessors' mean aligned values. This is the average from all participants. Intra-assessor reliability presented as the mean SD values in degrees for all participants. Calculated agreement between Dartfish and Vicon: the average RMSE and SD in degrees per segment for static and dynamic trials.

CALCULATION	ASSESSOR/TRIAL	GENERAL	HEAD	NECK	UT	MT	LT	UL	LL	PELVIS
DF-operator reliability			2.13° (0.7)	0.86° (0.4)	1.51° (0.4)	0.95° (0.4)	1.15° (0.6)	1.11° (0.5)	1.29° (0.3)	1.01° (0.5)
Inter-assessor reliability (Video)		0.99	0.97	0.92	0.98	0.94	0.98	0.98	0.98	0.99
Inter-assessor reliability (Vicon)		0.99	0.93	0.93	0.97	0.95	0.98	0.99	0.99	0.98
Inter-assessor reliability absolute values			2.03°	2.08°	2.14°	1.85°	1.28°	0.85°	1.29°	0.94°
Intra-assessor reliability	1		7.6°	7.1°	4.4°	5.2°	3.4°	2.2°	3.0°	2.1°
	2		9.0°	10.6°	7.4°	8.7°	5.9°	2.8°	4.7°	4.2°
	3		7.0°	6.5°	4.1°	5.2°	3.7°	2.2°	2.9°	2.5°
	4		8.0°	10.9°	6.8°	7.4°	5.4°	2.8°	4.4°	3.1°
	5		9.6°	11.6°	7.5°	8.9°	6.2°	2.9°	4.9°	4.0°
RMSE Absolute	Static		3.76° (2.3)	1.61° (1.6)	3.31° (2.8)	2.85° (1.8)	3.07° (2.1)	2.77° (1.6)	2.54° (1.5)	3.09° (2.3)
RMSE Detrended	Static		1.19° (0.5)	0.37° (0.3)	0.74° (0.3)	0.38° (0.2)	0.35° (0.2)	0.44° (0.4)	0.40° (0.2)	0.28° (0.2)
RMSE Absolute	Dynamic		8.35° (4.6)	5.50° (2.4)	5.90° (2.3)	2.85° (1.1)	2.48° (1.0)	2.22° (0.9)	2.87° (1.1)	3.53° (1.3)

RMSE Detrended	Dynamic	7.90° (4.2)	5.15° (2.3)	5.41° (2.3)	2.51° (1.0)	2.08° (0.9)	1.77° (0.7)	2.49° (1.0)	2.70° (1.0)