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Working towards an objective segmental assessment of trunk control in children with cerebral palsy

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Highlights

- This study developed an objective measure of head/trunk control in children with CP
- Simplified objective rules of an existing clinical test (SATCo) were generated
- These objective rules successfully mirrored the subjective assessment
- The SATCo is supported and validated by objective correlates
- The results give support to future full automation of trunk control measurement

Abstract

Background: Physical therapy evaluations of motor control are currently based on subjective clinical assessments. Despite validation, these can still be inconsistent between therapists and between clinics, compromising the process of validating a therapeutic intervention and the subsequent generation of evidence-based practice (EBP) guidelines. EBP benefits from well-defined objective measurements that complement existing subjective assessments.

Research question: The aim of this study was to develop an objective measure of head/trunk control in children with Cerebral Palsy (CP) using previously developed video-based methods of head/trunk alignment and absence of external support and compare these with the existing subjective Segmental Assessment of Trunk Control (SATCo).

Methods: Twelve children with CP were recruited and an average of 3 (±1.1) SATCo tests performed per child. The full SATCo was concurrently video-recorded from a sagittal view; markers were placed on specific landmarks of the head, trunk and pelvis to track and estimate head/trunk segment position. A simplified objective rule was created for control and used on videos showing no external support. This replicated the clinical parameters and enabled identification of the segmental-loss-of-control. The subjectively and objectively identified segmental-loss-of-control were compared using a Pearson Correlation Coefficient.

Results: An angular-threshold of 17° from alignment showed the minimum bias between the subjectively and the objectively measured segmental-loss-of-control (mean error =-0.11 and RMSE =1.5) and a significant correlation (r = 0.78, r^2=0.61, p<.01).

Significance: This study showed that simple objective video-based measurements can be used to reconstruct the subjective assessment of segmental head/trunk control. This suggests that a clinically-friendly video-based objective measure has future potential to complement subjective assessments and to assist in the generation of EBP guidelines. Further development will increase the information that can be extracted from video images and enable generation of a fully automated objective measure.

Key words

Trunk control; Cerebral palsy; Subjective assessment; Objective measure; Video-based method

1. Introduction

The term 'cerebral palsy' (CP) is commonly used to refer to a neurodevelopmental condition beginning in early childhood and persisting through the lifespan [1] resulting in disorganised and delayed neurological mechanisms of postural control, balance and movement [2, 3]. This motor compromise leads to functional limitations, especially when there is head and trunk involvement [4, 5]. Sitting is a fundamental ability that is the basis for many functional skills, but it relies on effective head/trunk control.

Current physical therapy assessments of controlled sitting ability for children with CP are based on tests that, although reliable, infer the motor control status from the subjective observation of functional abilities [6-10]. Most of these assessments consider the head/trunk as a single unit, ignoring its multi-segmental composition and overlooking the enhanced intervention planning and subsequent progression that can result from a segmental assessment [11].

There is a requirement in physical therapy, as in other medical and allied fields, for evidence-based practice (EBP). EBP integrates research evidence, individual clinical expertise and patient choice to allow decisions to be made about patient care [12]. EBP is desirable to help standardise intervention protocols and can provide validated support to decision making [12]. In order to validate an intervention, it is essential to have well defined assessments that, preferably, are objective; such assessments should incorporate the rules existing in the subjective clinical test while being clinically practical for both the patient and the therapist. Objective quantification aims to eliminate variability between and within assessors offering greater consistency of assessment between therapists and between clinics. Currently, objective clinical tests of head/trunk control for children with CP are not available.

This study takes the Segmental Assessment of Trunk Control (SATCo) as its start point since it provides a detailed assessment of trunk control status [6]. The SATCo systematically assesses control of the neutral, aligned sitting posture (minimal spinal curves) at six discrete head/trunk segmental levels and free sitting [6], following the process of typical development of upright head and trunk control [13-15]. It considers not only the alignment of the trunk in sitting but also the use of external support of the head/trunk or upper limbs (firm or light contact with an external surface, the child's own body or the child resting against the hands of the assistant) to determine if the child is actively demonstrating control: control is inferred if a child maintains or swiftly regains a neutral vertical posture [6, 16, 17].

The SATCo assesses the demonstration (or not) of static, active and reactive control at each segmental-level tested, starting with head control and moving downwards (caudally). Assessment of each of the trunk segmental-levels is achieved by providing encircling manual support directly beneath the trunk segmental-level under test (Figure 1). This manual support assures a stable and horizontally aligned pseudo-base for the segmental-level under test and the unsupported segments above it (Figure 1). The SATCo identifies the trunk segmental-level that is targeted for control training and this is defined as the uppermost (most cephalo) segmental-level where assured voluntary control is not demonstrated (segmental-loss-of-control). This study focussed on the static element of the SATCo (the ability to maintain an aligned posture above the manual support for minimum 5 seconds) since it is the basis on which active (anticipatory) and reactive (compensatory) control are acquired [18, 19] and is, therefore, of greatest clinical value [6].

Previous work [16, 17] has demonstrated that the two components of the SATCo i.e. i) alignment of the head/trunk and ii) the presence of contact with external surfaces, can be accurately classified from a subjective assessment and quantified using video recordings. The aim of this study was to develop, for the first time, an objective measure of head/trunk control in children with CP using previously developed video-based methods in combination with the SATCo criteria for the identification of head/trunk control in sitting and evaluate these against the existing subjective Segmental Assessment of Trunk Control (SATCo). The steps followed were to: i) formulate a simplified expression of the subjective rules suitable for an objective analysis; ii) test the extent to which these rules capture the subjective assessment; and iii) assess the extent to which the subjective assessment is supported and validated by objective correlates.

2. Methods

2.1. Ethics

Ethical approval for the 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 children (9 males, 3 females, mean age 4.52 years ±2.4, mean height 0.97m ±0.1, and weight 16.15kg ±7.5) were included in the study. The number of SATCo-tests per participant varied according to their routine specialist physical therapy clinic attendance. Detailed anthropometric measurements are provided in Table 1. All children had a diagnosis of CP (See Table 1 for GMFCS Levels). Children were included in this study if they showed problems of seated head/trunk postural control. Exclusion criteria were: fixed bony deformity or other structural problem of the spinal joints; uncontrolled epilepsy (more than one fit a day); other serious systemic illness; and if neither parent/guardian had sufficient understanding of written or spoken English to give informed consent.

A parent or guardian provided written informed consent on behalf of their child with written child assent where possible. To allow accurate palpation of anatomical landmarks for marker placement, children wore shorts as usual for their clinical assessments with girls wearing a crop top if required.

2.3. Procedures and Measurements

A full SATCo test was performed as part of each child's routine clinical review and was conducted according to the SATCo guidelines with particular attention to tester errors and to interpretation [6]. The SATCo systematically assesses control at six trunk segmental levels

(Head, Upper-Thoracic, Mid-Thoracic, Lower-Thoracic, Upper-Lumbar, Lower-Lumbar) and Free Sitting, within a single session. The presence of control was confirmed by: i) the child's ability to maintain an aligned posture of the unsupported trunk segments above the manual support; and ii) no use of the child's upper limbs for external support. In this study, the SATCo-test continued as low as the child's segmental trunk control allowed. The same assistant provided support for all children in the study.

Concurrent video was recorded at 25Hz from a video camera (JVC, HD Everio RX110) mounted on a levelled tripod on the right side of the child at a distance of 3.0m and a height of 0.70m. This view allowed recording of sagittal plane movements of the head and trunk. Markers were placed on specific landmarks of the head, trunk and pelvis, following the model previously developed (Figure 1) [16], where the trunk markers were small coloured blocks (2x2x2cm) used to improve the lateral visualization and tracking of the back landmarks (Figure 1).

Videos were screened to exclude those where the child used external support. SATCo-test videos were also excluded from analysis if a reference model of alignment could not be obtained i.e. the child could neither assume, nor be supported in, a neutral vertical posture at any of the segmental-levels tested.

Coordinates of landmarks from each video were obtained using the Dartfish marker tracking tool (Dartfish 7, TeamPro 7.0). One operator (first author) processed all videos. Following the methods established by Sánchez *et al.* [16], trunk segments were created using a customised Matlab (Mathworks, Cambridge, MA) code, with each segment defined as the vector joining two consecutive landmarks. Segment angles were calculated within the sagittal plane in relation to the aligned segment angle for that child. Following the published procedures [16], a model of the child's aligned sitting posture was created for each session; this was done by taking, for each segment angle, the mean value of all frames identified by the clinical assessors as aligned.

2.4. Data processing and analysis

For each trunk segmental-level tested during the SATCo, the static test was processed and is referred to as a ‘trial’. The segmental-loss-of-control for each SATCo-test was defined for all the trials using a subjective assessment and an objective video-based measurement analysis as described below.

2.4.1. Subjective evaluation of control: definition of concept and processing

The subjective SATCo rule credits static control at a given trunk segmental-level when the child maintains an aligned trunk posture in both sagittal and frontal planes for 5 seconds with the upper limbs free of external support [6]. This subjective rule allows a brief deviation of ≤ 20° from the aligned posture and additionally permits a brief loss of the child’s attention that is accompanied by a head turn provided that the aligned posture of the trunk is maintained [6].

SATCo-tests were evaluated in a random order. For each SATCo-test a median subjective value (mC) of the trunk segmental-loss-of-control was calculated from three independent clinical assessments of the video recordings. Four assessors, (3 to 20 years of experience) evaluated the videos; two assessors (C1 and C3) evaluated all the videos while the other two assessors rated the videos of the children for whom they were not the clinically responsible physical therapist; their assessments were combined to form C2. To calculate the consistent bias of each assessor, their mean difference from the median value was calculated.

2.4.2. Objective measure of control: simplified expression of the clinical rules

At each trial, i.e. each segmental-level tested, control was classified as demonstrated if the estimated segmental angle deviation from alignment for each of the unsupported segments remained below a specified angular threshold for the entire duration of the trial (5 seconds). For the complete SATCo-test, the segmental-level directly below the lowest segmental-level at which control was demonstrated, was classified as the trunk segmental-loss-of-control.

This objective classification of trials and assessment of segmental trunk control was repeated forty times, using angular thresholds of 1° to 40° with 1° increments.

2.4.3. Comparison of subjective and objective methods

The difference between the subjective and the objectively measured segmental-loss-of-control was calculated for each SATCo-test. This signed difference error was calculated for each angular-threshold. The mean error (ME) of all SATCo-tests provides a measure of systematic bias between subjective and objective assessment as a number of segmental-levels difference. The root mean squared error (RMSE) of all SATCo-tests quantified the random disagreement between the subjective (mC) and objective assessments. The objective threshold value with minimum bias (zero ME) and minimum random error (zero RMSE) was compared with the subjective 20° rule. Using the minimum bias angular-threshold, a Pearson Correlation Coefficient and r squared value were calculated to test whether, and to what extent, the subjective assessment was supported by objective evidence. For the subjective and objective assessments, a mixed effect linear model,

Segmental-loss-of-control ~ 1 + Repetition + (1 | Subject) (Wilkinson notation),

was used to test consistency with linear progression through repeated SATCo-tests.

3. Results

A total of 39 SATCo-tests were recorded, with 3 ±1.1 (average ±SD) SATCo-tests recorded per child. One child withdrew from the study after the first SATCo-test due to distress with the procedures. Of the 39 SATCo-tests, 28 met the selection criterion for objective analysis.

For all the subjective SATCo-tests, each assessor differed on average from the median subjective value (mC) by -0.39, 0.57 and -0.18 segmental-levels respectively (Figure) and showed root mean square difference from mC of 0.98, 1.25 and 0.63 segmental-levels respectively (Figure).

The ME and RMSE calculated between the subjective and the objectively measured segmental-loss-of-control showed that the minimum bias angular-threshold was at 17° with ME=-0.11 and RMSE=1.5 (Figure and Figure respectively). Using an angular-threshold of

17°, there was a high correlation (r = 0.78, r^2=0.61, p<.01) between the subjective and the objective assessments.

Figure shows the comparison of the subjective and the objective measure of the segmental-loss-of-control for each SATCo-test. The subjective assessments were more consistent with linear progression with repetition than the objective measurements (±0.8, ±1.6 residual standard deviation segmental-loss-of-control respectively, 0.13, 0.88 p-value repetition respectively, mixed effect linear model).

4. Discussion

The main aim of this study was to explore an objective measure of head/trunk control in children with CP. This exploration was based on the combination of previously developed video-based measurements with the existing subjective SATCo. Three main steps were followed to achieve this aim: i) the formulation of a simplified expression of the subjective rules suitable for an objective analysis; ii) testing the extent to which these rules captured the subjective assessment; and iii) assessing the extent to which the subjective assessment was supported and validated by objective correlates.

The subjective SATCo rule defines that control is demonstrated, at the head/trunk segmental-level tested, if i) there is no external contact/support and ii) all the unsupported segments remain below a nominal, subjectively judged, angular-threshold (~ 20 degrees). These rules have previously been published and the subjective SATCo assessment has been validated [6]. This study included only videos pre-screened for absence of external support and the expression of the angular-threshold rule was simplified for the objective method as described above. This study showed the subjective assessment to be consistent between clinicians and between sessions. Clinicians agreed with each other to within one segmental level (Figure and Figure) and were consistent with repetition to ±0.8 segmental levels (Figure). This variability mirrored the previous validation of the subjective SATCo [6] and thus provided a benchmark against which the objective analysis could be compared.

The objective rule for the angular-threshold identification of the segmental-loss-of-control defined that, at a specific segmental-level tested, all the unsupported segments had to remain below a specific angular-threshold; this angular-threshold was found to have the minimum bias at 17° (Figure and Figure). This objective rule captured a main parameter used by clinicians, but the simplification could not capture the clinicians' use of the 3D information contained in the 2D videos enabling a clinical 3D analysis, such as a brief head turn without loss of the aligned posture or the presence of light contact of the arms with the body [17]. The measured segmental-loss-of-control was thus based on the 2D information recorded from the two markers defining each trunk segment.

Taking the subjective assessment as a true score, this study showed a correlation between the subjective and the objective angular-threshold measurement of r=0.78 and this accounted for 61% of the variance in the subjective assessment (r^2=0.61). This significant correlation confirms that the objective angular-threshold rule largely captured the corresponding subjective assessment. It was, however, less consistent with repetition when compared with the subjective assessment, showing a residual variability of ±1.6 segmental-levels suggesting that the objective angular-threshold rule used may be an over-simplification and that the subjective assessment remains the gold-standard at this time.

While operating similar rules of evaluation, there are several reasons why the subjective assessment of video is more consistent than the current objective analysis. Clinicians have prior knowledge and experience and can use rules appropriately but more flexibly than the objective system, extracting more information from the videos than the current objective analysis. This current analysis used 2D tracking of the location of markers placed on the child: from the 2D videos the clinician saw and evaluated the whole segment, not just the marker, interpreting depth information from the images and thus performing a 3D analysis. The clinician can compensate for the visual occlusion of markers which contributed to the smaller consistency of the objective measure in this study. In order to replicate and surpass the subjective assessment, objective measurement of the segmental-loss-of-control should: i) incorporate analysis of the whole segment; ii) incorporate the assessment of external contact/upper limb support through the addition of an anterior view camera; iii) use depth information through the use of high-definition +depth cameras; and iv) incorporate more flexible rules. The success of 2D tracking analysis in capturing a large extent of the subjective assessment suggests that extraction of all the necessary information would be possible. More sophisticated methods [20-22] have the potential to provide this analysis.

This study provides clear support for, and validation of, the subjective SATCo and the clinical concepts on which the SATCo is based. A key finding of this study is that the subjective assessment of segmental trunk control can be reconstructed from simple objective observations (i.e. the presence of external support and the angular-threshold of the movement of trunk segments). Importantly, this was achieved using clinically-friendly video recordings. This result provides confirmation that the subjective assessment is related to the rules which are stated objectively. A key parameter is the angular threshold beyond which a segment is classified as not under control. The proximity of the objective value of this parameter (17°) to the subjective value (20°) links the subjective assessment closely to the objective measurements. The results confirm, in principle, the essential requirements for an objective system suitable for clinical operation.

The further development of a clinically-friendly, objective measurement of seated head/trunk control that is fully automated would have value both for children with CP and for adults with neurodisability. An automated system built using data from experienced physical therapists has the advantage of eliminating subjectivity in interpretation and analysis since physical therapists with less SATCo experience will then have the same interpretation of the SATCo as experienced users. Thus, the potential for inappropriate physical therapy treatment is reduced with potential cost savings. This elimination of subjectivity also means that consistency of the measure is maintained over the time of a prolonged therapy intervention and between different therapists in the same or in different clinics. This would provide an ideal route to validation, by research, of different therapeutic interventions and the support of evidence-based practice.

5. Conclusion

This study explored, for the first time, an objective measure of head/trunk control in children with CP combining the video-based techniques previously developed [16, 17] with the clinical subjective SATCo [6]. This study showed that determination of the angular-threshold of segmental trunk movement when combined with knowledge of the presence or absence of external support, can successfully provide the basis of an objective method for the identification of the segmental-loss-of-control. The objective measurements of this study give clear support to and validation of the subjective SATCo and the clinical concepts on which the SATCo is based

Further development of an objective clinically-friendly method for the assessment of control would benefit from the inclusion of 3D information, and methods which incorporate more fully the higher dimensional rules of clinical assessment.

Conflict of interest

None

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Table 1 Participants' anthropometric characteristics and Gross Motor Functional Classification System (GMFCS) levels

PARTICIPANT	Sex	GMFCS Level	Initial Age (years, months)	Initial Height (m)	Initial Weight (kg)
CH01	Male	IV	10y 11m	1.27	37.7
CH02	Female	IV	1y 11m	0.81	12.2
CH03	Male	III	4y 05m	1.04	16.5
CH04	Male	V	5y 1m	0.90	12.9
CH05	Female	IV	1y 9m	0.77	10.1
CH06	Male	V	5y 4m	0.99	14.7
CH07	Male	III	3y 11m	0.96	13.9
CH08	Female	IV	6y 1m	1.12	23.4
CH09	Male	IV	3y 3m	0.88	9.0
CH10	Male	III	4y 5m	0.94	12.4
CH11	Male	III	5y 6m	1.04	18.9
CH12	Male	IV	1y 10m	0.96	12.04
MEAN			**4.52**	**0.97**	**16.15**
SD			**2.42**	**0.13**	**7.51**

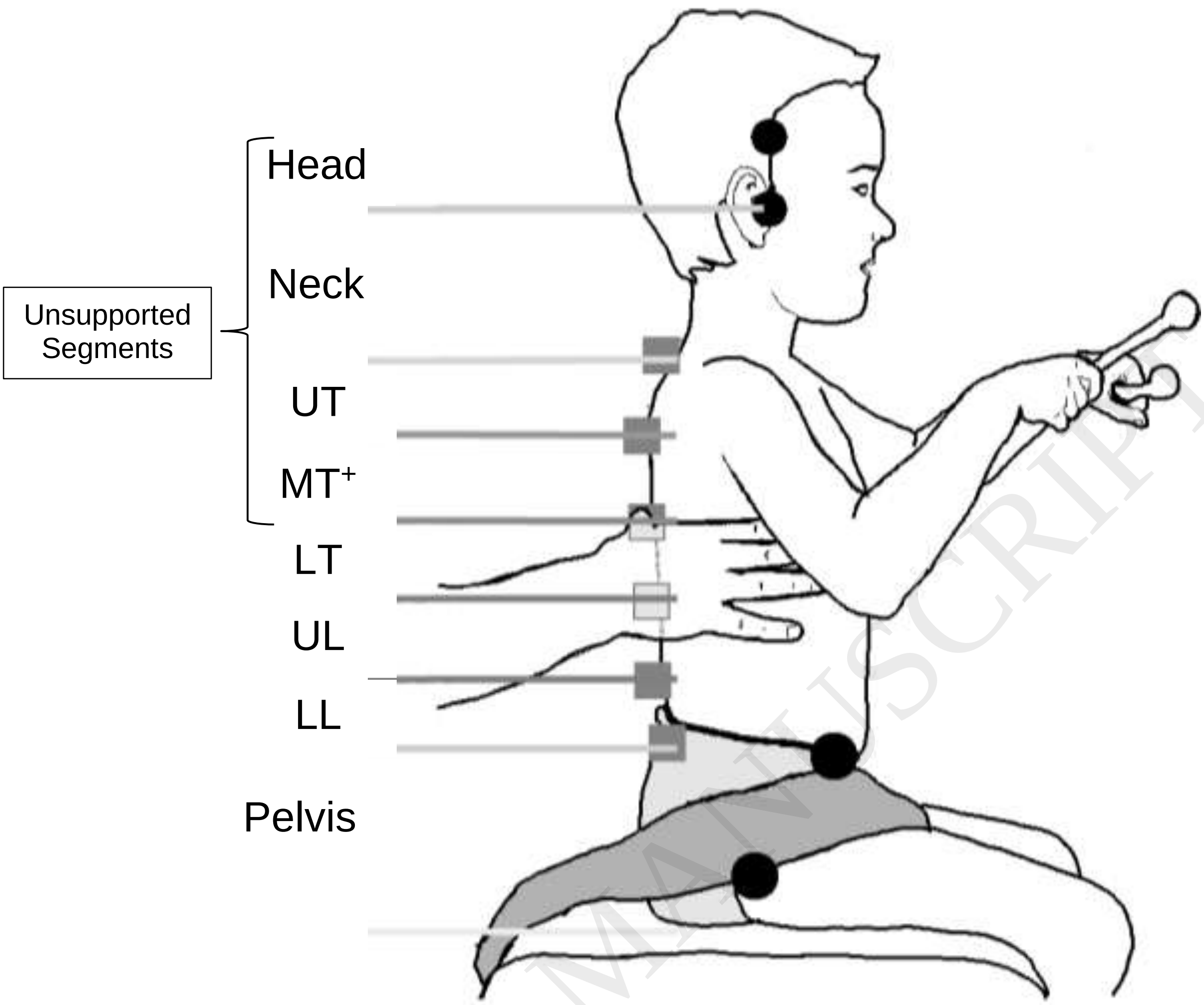

Figure 1 Example of testing control of the MT segmental-level. Marker location and limits of the trunk segments.

Squares show markers placed on the back of the participant: spinous process of the seventh cervical vertebra (C7), third, seventh and eleventh thoracic vertebrae (T3, T7 and T11), third lumbar vertebra (L3) and first sacral vertebra (S1). Dots show markers located on the side (and front of the child: right ear tragus, right temporal fossa (in a vertical line from the ear tragus when the head was in neutral position), greater trochanter and right anterior superior iliac spine (ASIS). Markers define trunk segments: Head, Neck, Upper-Thoracic (UT), Mid-Thoracic (MT), Lower-Thoracic (LT), Upper-Lumbar (UL), Lower-Lumbar (LL) and Free Sitting.

In this example, the testers' hands are positioned to test control at the Mid-Thoracic (MT^+) segment. Thus, the Head, Upper-Thoracic (UT) and MT are unsupported segments.

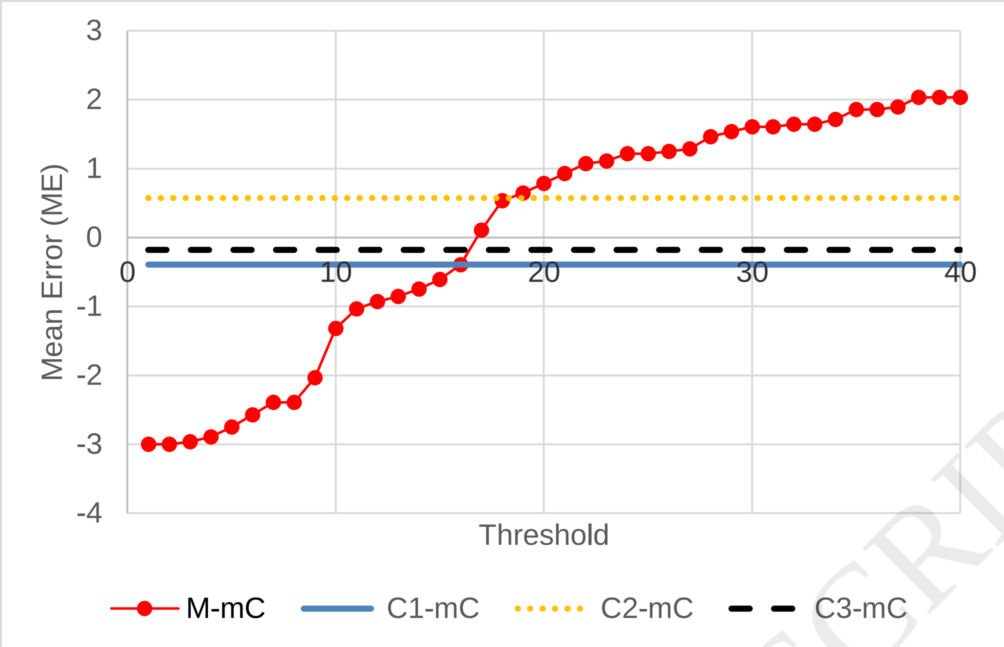

Figure 2 Calculated mean error (ME) for threshold values 1-40°.

Showing for each threshold value 1-40° the mean error (ME) between the objective assessment and the median of the assessors (M-mC red dots). For reference, for each assessor, the difference between the subjective assessment and the mC is included (C1-mC blue bold line, C2-mC yellow dotted line, C3-mC black dashed line).

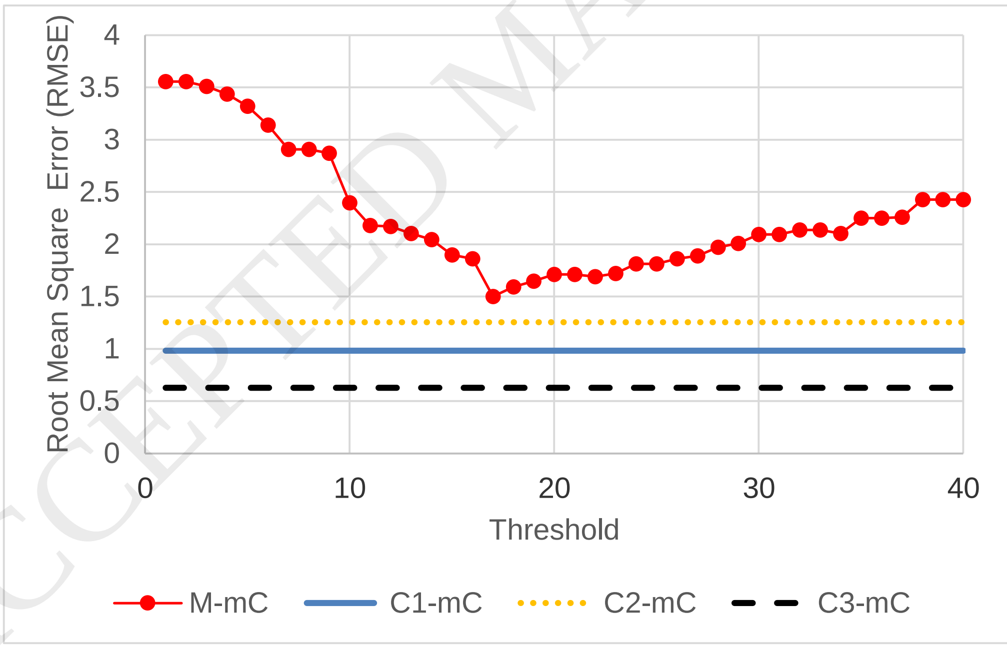

Figure 3 Calculated Root Mean Square Error (RMSE) for threshold values 1-40°.

Showing for each threshold value 1-40° the Root Mean Square Error (RMSE) between the objective assessment and the median of the assessors (M-mC red dots). For reference, for each assessor, the difference between the subjective assessment and the mC is included (C1-mC blue bold line, C2-mC yellow dotted line, C3-mC black dashed line).

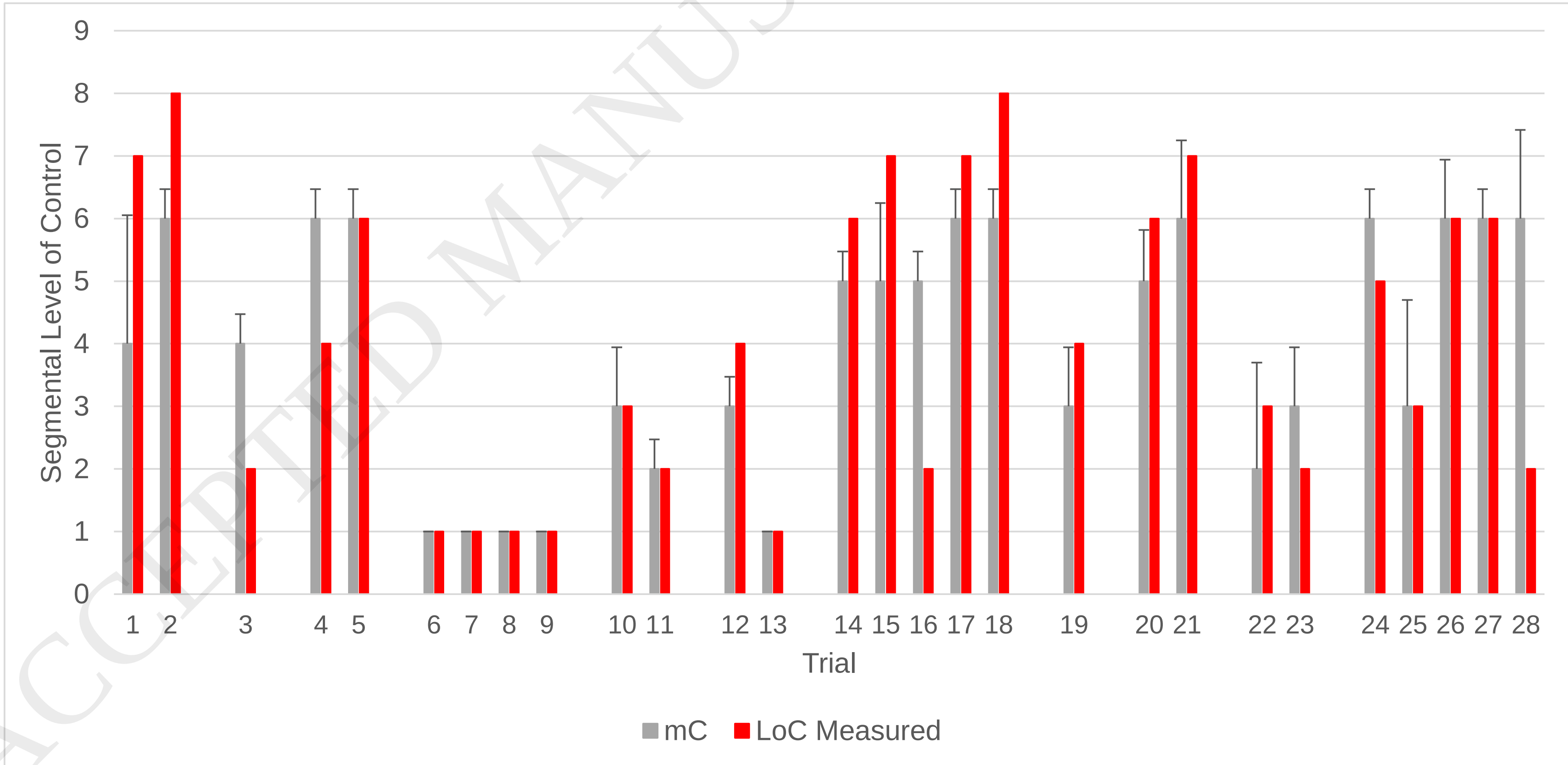

Figure 4 Clinical vs measured assessment of the segmental loss of control.

Showing the median value of the segmental-loss-of-control for the assessors (mC, grey) against the objective measured segmental-loss-of-control (LoC Measured, red). Error bars show the standard deviation between assessors. Values in the 'y' axis represent the clinical segmental-loss-of-control 1 = Head, 2 = Upper-Thoracic, 3= Mid-Thoracic, 4 = Lower-Thoracic, 5 = Upper-Lumbar, 6 = Lower-Lumbar and 7 = Full Trunk; the objective system infers 8 = Full Trunk control present. The independent sessions relate to the participants as follows: CH01 = 1,2; CH02 = 3; CH03 = 4, 5; CH04 = 6-9; CH05 = 10, 11; CH06 = 12, 13; CH08 = 14-18; CH09 = 19; CH10 = 20, 21; CH11 = 22, 23; CH12 = 24-28.