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The potential of an automated system to identify the upper limb component of a controlled sitting posture

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ABSTRACT

Full trunk control in sitting is demonstrated only when the head-trunk are aligned and upper limbs remain free of contact from mechanical support. These components represent a Controlled Kinetic Chain and can be evaluated in people with neuromotor disability using the Segmental Assessment of Trunk Control (SATCo) when a therapist provides manual trunk support at different segmental levels. However, the SATCo, as with other clinical assessments of control, is subjective. The SATCo was translated to objective rules relating the position of the hands and elbows to the head-trunk and then tested to determine the extent to which this automated objective method replicated the clinical judgement.

Clinical evaluation used video to determine whether the upper limb was free of mechanical support while the objective evaluation used 3D motion capture of the trunk and upper limbs with a classification rule. The agreement between clinical and objective classification was calculated for three conditions of a distance-from-support-surface threshold parameter in five healthy adults and five children with cerebral palsy.

The unfitted (zero-threshold values) method replicated the clinical judgement in part (68.26% ± 15.7, adults, 48.3% ± 33.9 children). The fitted (level-of-support determined) agreement showed that the process could be refined using trial specific parameters (88.32% ± 5.3 adults, 89.84% ± 10.2 children). The fixed-values agreement showed high values when using general group parameters (80.80% ± 3.1 adults, 74.31% ± 21.5 children).

This objective classification of the upper limb component of trunk control largely captures the clinical evaluation. It provides the first stages in development of a clinically-friendly fully automated method.

1. Introduction

Independent unsupported sitting, with a vertically aligned head and trunk (head-trunk) is a milestone of typical development and requires full motor control of the head-trunk [1]. Reduction or absence of head-trunk control can result from neuromotor disability such as cerebral palsy (CP) with the consequent lack of independent sitting ability leading to functional limitations [1].

The head-trunk is a kinetic chain of segments comprising the head and neck and successive trunk segments to the pelvis. These axial segments branch into the upper limbs. The term 'Controlled Kinetic Chain' (CKC) denotes the biomechanical chain as a controlled entity and is used in the context of determining the neuromuscular control status of individual joints within that chain [2]. In independent unsupported sitting, full motor control of the whole kinetic chain of the head-trunk and upper limbs is demonstrated only when there is no end of range mechanical support at any axial joints or from external objects other than the primary support surface. This control without mechanical support is termed an Open-CKC [2]. In the trunk, a sitting posture that is, for example, slumped into full lumbar flexion with passive end of range mechanical support from intervertebral ligaments obviates the need for active control; it is termed a Closed-CKC [2]. This closure is assessed clinically by analysis of trunk alignment [3]. Use of the upper limbs or an external object to support the trunk mechanically can also remove the need for active control and is also termed a Closed-CKC [2]. This closure is assessed clinically by observation of the upper limbs in relation to the trunk and external objects. For example, if a person rests one hand on his/her thigh, then this can help maintain a sitting posture in the presence of poor trunk control even if the trunk is apparently aligned.

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$$OpenCKC = all\left(\begin{bmatrix} d1 \\ d2 \\ d3 \\ d4 \end{bmatrix} > t\right)$$

where t is an adjustable threshold

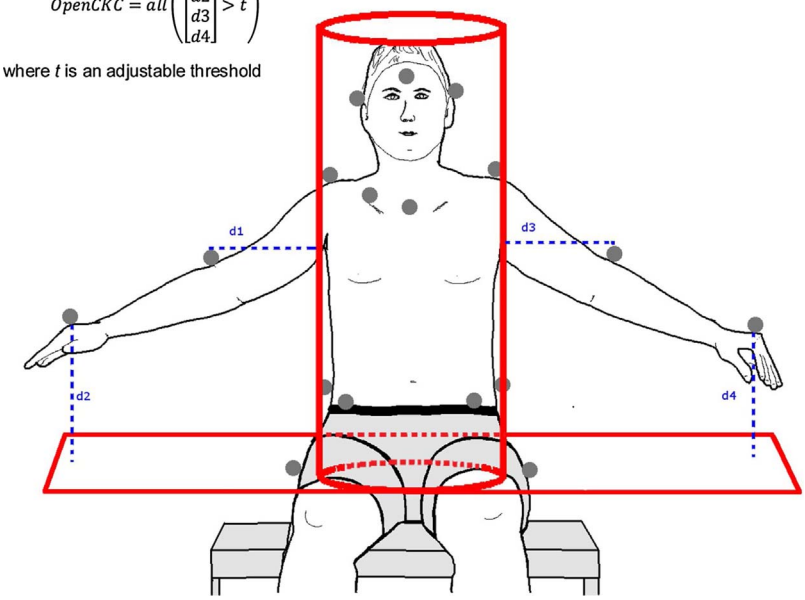

Fig. 1. Marker locations and supported-volume.
Dots show Vicon marker locations: forehead, middle of the right clavicle, left and right acromion process of the scapula, lateral condyle of the humerus (elbow), head of the third metacarpal bone, Iliac crest, anterior superior iliac spine and greater trochanter. The red cylinder and plane represent the volume that defined a Closed-CKC. Dashed blue lines show the shortest distances ($d_{1\text{-}4}$) from each of the hands and elbows to the supported-volume surface for this given posture. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Assessment of trunk control should thus consider both alignment of the head-trunk segments and use of the upper limbs. In neuromotor disability such as CP, motor control is usually assessed through comparison with typically developing children and inferring control status from functional activities [4,5] or through a child's ability to maintain a balanced posture either statically and/or dynamically [6,7]. The Segmental Assessment of Trunk Control (SATCo), uniquely assesses CKC status at six trunk segmental levels and free sitting [3]. Although it provides greater information about motor control strategies, in common with other clinical tests, it is subjective. Objective quantification is desirable since it is repeatable, eliminates variability between and within assessors and offers the potential for quantifying clinical changes over time. In order to complement a clinical assessment, an objective automated system should incorporate the rules existing in the specific clinical test. It should also be practical for clinical use and thus 'clinically-friendly' for both for the child and the therapist.

A method for quantifying postural alignment in sitting has been developed that uses a video-based system [8]. The aim of the study reported here was to explore the potential for an automated method to establish use of the upper limb component of the CKC. This was achieved by: (i) defining the clinical rules to assess the upper limb kinetic chain status through video recordings; (ii) formulating a method to replicate the clinical rules with quantities that could be measured and classified objectively; and (iii) testing the extent to which the objective method replicates the clinical judgement. Initial development was performed with a group of healthy adults to eliminate the complications associated with compromised motor control. The system was then tested in a real clinical context with a group of children with CP.

2. Methods

2.1. Ethics

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

2.2. Participants

Two groups of participants were recruited: an adult group (Adult-group) of 3 males, 2 females, mean age 28 ± 4 years, mean height 1.72 m ± 0.09, and weight 73.1 kg ± 10.2 tested at MMU; and a child group (Child-group) of 4 males, 1 female, mean age 8.4 ± 4.62 years, mean height 1.1 m ± 0.27 and weight 24.16 kg ± 10.8 tested at The Movement Centre (TMC, Oswestry, Shropshire, United Kingdom). All adults were healthy with a body mass index < 29 kg m^{-2}. All children had a diagnosis of cerebral palsy and were participating in Targeted Training (TT) therapy at TMC. All adults gave written informed consent for their participation. Children's parents provided written informed consent with child assent where possible. To allow accurate palpation of anatomical landmarks for marker placement, adults wore a tight pair of shorts with men leaving their upper body free of clothing and women wearing a tight vest. Children wore only their underwear, nappy or shorts as usual for their clinical assessments.

2.3. Procedures

All participants sat in an upright aligned posture on a bench free of back or arm support. The height of the bench was adjusted to ensure each participant's feet were flat on the floor with knees and hips flexed at 90°. Adults performed a sequence of twelve arm movements that represented both no-support, such as both arms in the air to the sides or the front, and support/contact such as hands on the bench, legs or head. Six trials were recorded per participant with different segmental levels of trunk control tested (Upper-Thoracic, UT; Mid-Thoracic, MT; Lower-Thoracic, LT; Upper-Lumbar, UL; Lower-Lumbar, LL; and free sitting, FS) following the SATCo guidelines [3]. The trunk was supported manually directly beneath the tested segment resulting in 'unsupported segments' above the manual support: arms (tip of the fingers to axillae), head and unsupported segments of the trunk.

Children were recorded during the routine SATCo performed as part of their TT therapy.

2.4. Apparatus and measurements

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