Gait & Posture 30 (2009) 138–143

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Winner of the ESMAC 2008 Best Paper Award

Evaluation of clinical spasticity assessment in Cerebral palsy using inertial sensors

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This paper was selected by an ESMAC Reading Committee headed by Professor Maria Grazia Benedetti. The present paper was edited by Dr. Tim Theologis.

ARTICLE INFO

Article history:
Received 15 March 2009
Received in revised form 28 April 2009
Accepted 18 May 2009

Keywords:
Muscle spasticity
Cerebral palsy
Rehabilitation
Movement analysis
Biomedical engineering

ABSTRACT

Spasticity is clinically assessed using goniometry to measure the joint angle of the catch (AOC) during fast passive muscle stretch. The precision and accuracy of the goniometric AOC measurements are questionable, because of the inevitable joint repositioning after occurrence of the catch.

This study aims to evaluate the use of goniometry in estimating the AOC in spasticity assessment of the medial hamstrings, soleus and gastrocnemius in twenty children with Cerebral palsy (CP), using inertial sensors (IS) as reference system.

The IS were initially validated with an optoelectronic system to measure 3d-orientation and proved to be accurate within 1°.

To evaluate the precision and accuracy of the goniometry, the joint angle measured with the goniometer after repositioning was compared to the joint angle measured simultaneously with the IS, and to the true AOC, detected and measured with the IS during the fast muscle stretch.

Results showed that goniometry is an imprecise method to measure the true AOC in spasticity assessment. The error is mainly due to joint repositioning after the fast muscle stretch. For spasticity assessment, it is advised to apply inertial sensors when a precise measurement of the angle of catch is required.

1. Introduction

Cerebral palsy (CP) is the most common motor disability in childhood, characterised by a persistent disorder of posture or movement due to a non-progressive disorder of the immature brain [1]. Spastic paresis is the most common type of CP affecting motor ability.

Clinical assessment of spasticity is important in children with CP, not only to diagnose spasticity, but also for clinical decision-making and to evaluate the effect of treatment. To distinguish spasticity from other impaired muscle functions a robust definition of spasticity, an unambiguous test protocol and reliable instruments are crucial.

The most commonly used definition of spasticity was described by Lance (1980): "a motor disorder characterized by a velocity dependent increase in tonic stretch reflexes (muscle tone) with exaggerated tendon jerks, resulting from hyper excitability of the stretch reflex, as one component of the upper motor neurone syndrome" [2].

Different clinical scales have been developed and used to assess spasticity during physical examination, such as the (Modified) Ashworth Scale [3], the (Modified) Tardieu Scale (TS) [4], the Pendulum Test [5] and the Spasticity Test (SPAT) [6]. Only the TS and the SPAT (a more simple version of the TS) are based on Lance's definition. In these tests, the range of motion (ROM) is assessed by slow passive stretch of the muscle of interest. Subsequently, a fast passive stretch of the muscle is performed to detect a catch. The catch is defined as a sudden appearance of increased muscle activity in response to the fast passive stretch, which leads to an abrupt stop or increased resistance during the joint movement, at a certain angle (AOC: the angle of catch) before the end ROM is reached [7,8]. Both in literature and clinical practice the catch is accepted to be the dominant phenomenon of spasticity [6–9]. Boyd and Graham [4] described that the dynamic component (i.e. the difference between ROM and AOC) can be used for treatment decisions of spasticity.

The AOC is usually measured using goniometry. To assess the AOC, the examiner has to reposition the joint *after* the fast muscle stretch in the position where the catch occurred [4,6]. A second examiner then uses the goniometer to measure the joint angle. Precision and accuracy of goniometric measurements of joint

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doi:10.1016/j.gaitpost.2009.05.011

angles have been questioned [10,11]. Repositioning and goniometry may introduce error that affect precision and accuracy of the AOC estimation.

Accurate measurement of the AOC during the fast passive muscle stretch could be performed using an optoelectronic marker system (OS). However, during physical examination, markers are easily hidden. An alternative is the use of lightweight inertial sensors (IS), containing tri-axial accelerometers, gyroscopes and magnetic sensors, developed for ambulatory measurements of 3d-orientation of human body segments [12–19]. In comparison to OS the first generation IS are reported to be accurate within 3° Root Mean Square (RMS) [12,13,19], and appear to be adequate for the accurate measurement of fast rotation.

The aims of the present study were (1) to technically validate the IS for measuring 3d-orientation during spasticity assessment; and (2) to evaluate the precision and accuracy of goniometry to estimate the AOC during fast muscle stretch in the assessment of spasticity in children with CP, using IS as a reference system to obtain joint angles. We hypothesized that IS are valid to measure 3d-orientation and can be used for estimation of the AOC. Secondly, we hypothesized that goniometry is an imprecise and inaccurate method to measure the AOC, mainly due to incorrect repositioning of the joint.

2. Methods

2.1. Subjects

One healthy subject (26 years; 50 kg; 150 cm) participated in the validation study. The goniometry study included twenty children with spastic CP (5–14 years; 35 ± 14 kg (mean ± standard deviation); 139 ± 19 cm; GMFCS range I–IV [20]). The Medical Ethics Committee of the VU University Medical Center, Amsterdam, approved the study. Full written informed consent was obtained from all parents and children aged 12 years and older.

2.2. Procedure and instrumentation

In both studies, fast passive muscle stretch of the medial hamstrings, soleus and gastrocnemius, according to the test protocol of the SPAT [6], was undertaken by an experienced examiner, starting from standardised joint positions (see Table 1). In the validation study, the right leg was tested. In the goniometry study, the affected (hemiplegia), the most affected (asymmetrical diplegia) or the right leg (symmetrical diplegia) was tested. All muscles were tested three times.

Two IS [MT9, Xsens Technologies, Enschede, The Netherlands] tracked the motion of the proximal and distal segments during the tests (see Fig. 1 and Table 1), with a sample frequency of 100 Hz. Each IS was attached securely to the segment, using neoprene straps, to prevent change of orientation of the sensor with respect to the segment. All tests were performed on a couch with a wooden frame, to avoid magnetic disturbances in the magnetometers in the IS. Prior to the actual tests, a measurement was performed in the reference position for calibration purposes (see Table 1).

In the validation study a cluster of three Optotrak markers (OS) [Optotrak 3020; Northern Digital Inc., Waterloo, Ontario, Canada] was placed on each IS to track its 3d-orientation simultaneously, with a sample frequency of 100 Hz. Data of the IS and the OS were synchronized afterwards using cross-correlation [21].

In the goniometry study, the experienced examiner performed the fast muscle stretch and repositioned the joint in the position where the catch first appeared (the encountered AOC). Subsequently a second experienced examiner used goniometry to measure the joint angle. For the medial hamstrings the knee angle was measured using the Gollehon Extendable Goniometer [Lafayette Instrument Company, IN 47903]; for the soleus and the gastrocnemius the ankle angle was measured with the Biplane Goniometer [Lafayette Instrument Company, IN 47903 USA]. To aid correct placement of the goniometer, bony landmarks were marked. To compare the goniometry with the IS, the moment of goniometric readout within the IS signals were marked using a footswitch signal.

2.3. Data analysis

2.3.1. Validation study

To validate the IS, nine trials of joint motion, three for each muscle, were analysed. To determine the difference of the IS with respect to the OS, the mean RMS difference in 3d-orientation angles, averaged for the three trials of each muscle, was used. An RMS difference less than 3° was considered to be acceptable. For comparison purposes, the 3d-orientation of the IS, expressed in its own global coordinate system defined by the local magnetic north and the gravity, was transformed into 3d-orientation in the global coordinate system of the OS. Orientation angles (*x*,*y*,*z*-Euler angles) of the IS and the OS markers were then obtained from decomposition of 3d-orientation.

2.3.2. Goniometry study

To compare the goniometric measurement of the AOC with the IS as a reference system, the units of measurement of goniometry

Table 1
The Spasticity Test.

		Hamstrings	Soleus	Gastrocnemius
Joint		Knee	Ankle	Ankle
Segment	Proximal	Thigh	Shank	Shank
	Distal	Shank	Foot	Foot
Patient Position	Supine/prone	Supine	Supine	Supine
	Hip	90° flexion	90° flexion	Extension
	Knee	Maximal flexion	90° flexion	Extension
	Ankle	Not relevant	Maximal plantar flexion	Maximal plantar flexion
Joint motion		Knee extension	Ankle dorsal flexion	Ankle dorsal flexion
Joint angle of catch	Name	(Popliteal) Knee angle	Ankle angle	Ankle angle
	Reference	Full extension is 0°	0° dorsal/plantar	0° dorsal/plantar
Reference position	Supine/prone	Supine	Supine	Supine
	Hip	90° flexion	90° flexion	90° flexion
	Knee	90° flexion	90° flexion	90° flexion
	Ankle	Not relevant	0°	0°