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Test retest reliability of computer-based video analysis for the assessment of postural control in individuals with cerebral palsy

Graduate thesis in Medicine

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Abstract

BACKGROUND: Deficits in the control of posture is an important aspect of CP, as defined by SCPE and children with CP often exhibit activity limitations that are associated with postural control problems. However, there is a lack of adequate tools for assessing postural control in individuals with CP, and there is limited documentation of the measurement properties of the existing tools.

AIM: The first aim of this study was to explore if variables obtained using a computer-based video analysis software could be used to assess postural control. The second aim of this student thesis was to explore the test-retest reliability properties of these variables in individuals with CP and TD individuals 8-29 years of age.

METHOD: Thirteen individuals with CP and 24 typically developing (TD) individuals, 8-29 years, were asked to stand still while three videos recorded their movements from the side. The movements in the video recordings were quantified, using a computer-based video analysis.

RESULTS: In the explorative part of this study we found that the variables calculated by the computer-based video analysis that best correlated with the clinical assessment of postural control in the individuals with CP was the mean value of the centroid of motion (Cx_{mean}) and its standard deviation (Cx_{SD}) in the horizontal axis. The centroid of motion is the spatial centre of all movements in the picture. In further analyses, the Cx_{mean} showed the best correlations with GMFM-66, a clinical assessment tool for postural control, while the correlations were low for Cx_{SD}.

In the second part, I found that when we included all participants in the analyses, the ICC values of Cx_{mean} ranged between 0.89 and 0.93, and of Cx_{SD} ranged between 0.92 and 0.93. The ICC values of Cx_{mean} and Cx_{SD} were higher with more narrow confidence intervals when two video recordings, each of 30 seconds duration, were included, than when a third video recording of two minutes was included in the calculations. The ICC values of Cx_{mean} and Cx_{SD} were nearly identical when applying ICC(1,1) and ICC(3,1).

The standard error of measurement (SEM) for Cx_{mean} ranged from 2.2 (4 %) to 3.1 (6 %), expressing a small degree of measurement error. The smallest detectable difference (SDD) for Cx_{mean} ranged from 6.0 (10 %) to 8.5 (15 %). However, the SEM values for Cx_{SD} ranged from

0.3 (14 %) to 0.7 (27 %), and the SDD values from 0.7 (40 %) to 2.0 (76 %). The Bland-Altman plots for Cx_{mean} verifies graphically the consistency of the 3 video recordings. The Bland-Altman plots for Cx_{SD} verifies graphically the consistency of the measures in TD group, while it illustrates a spread in the values in the individuals with CP. The difference between the CxSD values from the two recordings were larger in the individuals with CP than in those with TD.

CONCLUSION: We found that the variable Cx_{mean} from the computer-based video analysis software describes certain aspects of postural control in individuals with CP, 8-29 years. The test-retest reliability of this variable is good. However, more studies are required to further evaluate this method and to explore if other variables of the computer-based video analysis may better describe other aspects of postural control.

Contents

Abbreviations

APA = Anticipatory postural adjustments

CNS = Central nervous system

CoM = Centre of mass

CoP = Centre of pressure

COSMIN = Consensus-based standards for selection of health measurements instruments

CP = Cerebral palsy

Cx_{mean} = mean location of centroid of motion in the horizontal axis

Cx_{SD} = standard deviation of the displacement of centroid of motion in the horizontal axis

GMFCS = Gross Motor Function Classification System

GMFM-66 = Gross Motor Function Measure, a clinical tool designed to assess gross motor function in children with CP

ICC = Intraclass correlation coefficient

QoM = quantity of motion

SDD = Smallest detectable difference

SEM = Standard error of measurement

TD = Typical developing individuals

1. Cerebral palsy

1.1 Definition and epidemiology

The syndrome of cerebral palsy (CP) is defined as a group of permanent disorders of the development of movement and posture, resulting from non-progressive injuries to the immature foetal or infant brain(1). The motor disorders are often accompanied by other comorbid conditions regarding e.g. communication and cognition and secondary musculoskeletal problems(1). The prevalence rate of CP is 2.5 per 1000 live births in Norway(2), and range between 2.0 and 2.5 per 1000 children in the western world(1). These numbers have remained stable the last decades(1), and children with CP are the largest diagnostic group treated in paediatric rehabilitation(3).

1.2 Impairments

The abnormal motor activity and posture characterizing CP results in varying degrees of difficulties when trying to perform voluntary complex and simple movements(1). The motor impairments seen in individuals with CP is clinically characterized as an upper motor neuron syndrome including both positive and negative signs(4). The positive signs result from absent inhibition from cortical circuits, and include spasticity, dyskinesia, hyperreflexia, retained developmental reactions, and secondary musculoskeletal malformations(4). Negative signs, such as weakness, poor coordination of movements, poor walking ability, and balance, are due to lack of proper sensorimotor control mechanisms(4). The impacts of CP on stance and postural control will be discussed later.

CP is often accompanied by other comorbid conditions(5-7). Andersen et al. found that 31 % children with CP were considered mentally retarded, 38 % had impaired or severely impaired speech, 4 % had severely impaired hearing, 5 % had severely impaired vision, 34 % were unable to eat independently, and 28 % had active epilepsy(7). Other frequent impairments among children with CP include bladder control problems, behaviour problems, pain, sleep disorders, drooling and hip displacement(5). Co-occurring impairments like these are more frequent, and they often cause more limitations, in individuals with increased severity of the motor handicap(5). The only exceptions are behaviour disorders (increased prevalence when milder levels of physical disability) and pain (likely to be present at all levels of physical disability)(5).

1.3 Classification

Two classifications frequently used to describe the impairments in individuals with CP are, firstly, by limb distribution and type of impairment, and secondly, by the impact on gross motor function according to the gross motor function classification system (GMFCS)(6). The Surveillance of CP in Europe (SCPE) presented an European classification of CP, that divides CP into the subtypes spastic, ataxic and dyskinetic as well as unclassifiable cases(8). All three subtypes is characterized by an abnormal pattern of posture and/ or movement(8). The spastic CP is usually characterized by increased tone and pathological reflexes, and may be either bilateral when involving limbs on both sides, or unilateral if limbs on only one side is involved(8). The ataxic subtype is characterized by movements performed with abnormal force, rhythm, and accuracy. The dyskinetic CP is dominated by involuntary, uncontrolled, recurring, occasionally stereotyped movements(8).

The GMFCS was first presented in 1997 as a new tool for evaluation of gross motor function based on new research and existing classification systems(9), and it has been further developed since(6). The five levels are as follows:

I	Walks without limitations
II	Walks with limitations
III	Walks using a hand-held mobility device
IV	Self-mobility with limitations. May walk short distances
V	No means of independent mobility

Further classifications have been proposed for fine motor functions (BFMF and MACS), for feeding difficulties(10) and for speech problems(11).

1.4 Aetiology

The aetiology of CP is multifactorial. Although one factor may be sufficient to cause CP, more often it is the presence of multiple risk factors that leads to CP(12). In a Norwegian cohort study the factors most often related to CP were prematurity (44 % of the CP cases), maternal disease (43 %), induction of labour (30 %), low Apgar score (24 %), and small for gestational age (14 %)(13). In 25 % of the CP cases no risk factors were detected(13). Prematurity is not itself a cause of CP, but it is the most important risk factor(1). This is due to the different complications that may arise because of prematurity, and in some situations the cause of the premature delivery (i.e. an intrauterine infection) may actually contribute to both the development of CP and the premature delivery. The prevalence of CP increases with decreasing gestational age(14). In a meta-analysis the prevalence ranged between 1.2 and 1.6 per 1000 live births when gestational age was more than 36 weeks, and between 70 and 180 per 1000 live births when gestational age is less than 28 weeks(14). Despite this increased risk among children born preterm, approximately 50 percent of children with CP is born at term(13).

The pathology in the brain can be due to one or several events prior to conception, during the pregnancy, during or close to birth or after the neonatal period(1). The associated causes of CP vary somewhat according to gestational age group, and clinical CP subtype(12).

Although there are very few known direct genetic causes for CP, these are increasingly implicated in the understanding of the syndrome(1, 15). As well as the single gene Mendelian disorders found to cause CP, there is also observed an increased familial risk for CP(15), and certain combinations of genetic variation that are associated with differences in the clinical manifestations of CP(16). Other factors prior to conception, such as adverse socioeconomic status and maternal factors such as diabetes, rhesus isoimmunization and anti-phospholipid syndrome, can also contribute to increased risk for CP(1).

Interference with normal brain development in utero is the major cause of CP(15). Antenatal causes include chromosomal abnormalities, congenital infections, and a wide range of malformations and diseases in the nervous system(1). While much is known about causes of CP late in the pregnancy(1), there is a paucity of identified and identifiable causes in the first half of gestation, resulting in many cases of CP with no proven aetiology(1). Periventricular leukomalacia is an injury to the foetal brain, due to brain vulnerability before 32 weeks of gestation(1, 17). Periventricular leukomalacia refers to white matter atrophy, ventriculomegaly, cyst formation, resorption and gliosis in the "watershed" areas of the white matter, where perfusion is minimal(17). It attributes to a large proportion of CP in preterm children, and the causative event can occur both before, during or after birth(1). This being an ischaemia reperfusion injury, contributing factors include hypotension, infection and hypocarbia(17). Prematurity also increases the risk of intraventricular haemorrhage and periventricular venous infarction, both which can result in brain damage due to increased intracranial pressure(1).

Events during or close to the delivery of a child can also cause CP, although this percentage is assumed to be smaller than earlier assumed(1). In the perinatal period, two important mechanisms contributing to development of CP are hypoxic-ischaemic injury and stroke(1). Birth asphyxia can cause hypoxic-ischaemic injury as a consequence of perfusion failure in the brain(1). Perinatal stroke is the occlusion of a major cerebral blood vessel, due to embolism or thrombosis, may result in CP in the child(1). Other less frequent causes of CP in the perinatal period is hyperbilirubinemia, hypoglycaemia, birth trauma, and neonatal infection(1). There is no agreement at which age a postneonatal brain impairment can be sure not to cause CP, although it is thought to be around the age of two years(1). Postneonatal causes contributes to approximately 6 percent of cases of CP, and can be due to e.g. near drowning, near miss-SIDS and bacterial infections(7).

1.5 Prognosis

The life expectancy in individuals with CP depends on the severity of the mental, manual, ambulatory and visual impairments. Survival is only marginally reduced if all these impairment domains are mild, while the presence of severe impairments greatly reduces the life expectancy, approximately in proportion to the number and severity of the

impairments(15). Prognostication about the gross motor progress in children with CP is possible, based on 5 distinct motor development curves defined for the 5 GMFCS levels(18).

2. Postural control

2.1 Definitions

Postural control can be defined in several ways, but a recent Delphi study revealed consensus for the following definition: Postural control is the control of the body's position in space for postural orientation and postural stability(19). Postural orientation is the ability to maintain an appropriate relationship between the body segments to each other, to the task, and to the environment (19). Posture is a term widely used to describe the biomechanical alignment of the body, as well as the orientation of the body to the environment(20).

Postural stability is the ability to maintain the centre of mass (CoM) within the limits of the base of support (BoS). The CoM is defined as a point that is at the centre of the total body mass, and will in humans be located to the trunk(20). The area of the contact between the body and support surface, or the area enclosing all the contact points, constitutes the BoS(21). If the CoM of a person is displaced out of the area of the BoS, he or she will become unbalanced and eventually fall *(21).* Thus, the ability of a person to balance, is related to the position of the CoM, and the area of the BoS of that person(21). Despite there is no universally accepted definition of human balance(21), by health professionals it is agreed to be equal to postural stability(19, 20). As it is difficult to assess the behaviour of CoM, most studies measures the trajectories of the centre of the pressure (CoP) instead(22). The CoP is the origin of the ground reaction vector, which can be measured using a force plate placed on the ground(20, 23).

To preserve stability is a dynamic process. In order to do so, one can either relocate the CoM trough adjustments of the body segments in relation to each other, or change the BoS, for example by taking a step(20). Whereas most of the daily activities demands on the postural control system, some activities have strict requirements considering postural orientation, while other require less postural orientation and excellent/ better postural stability(20).

2.2 Physical mechanisms in postural control

The maintenance of postural control is challenging, even during daily activities, because it requires a complex interaction of the sensory system, the central nervous system (CNS), and the muscle skeletal system(22-24). These physical mechanisms underlying postural control will be discussed in the following. The control of posture is an active process involving most

of the nervous system, especially the cerebellum, the basal ganglia and the cortex of the large hemispheres(22).

2.2.1 Sensory nervous system

The sensory nervous system is important in the control of posture(20, 22, 24). Visual inputs regarding the position and motion of the head is one of the most important sources of information for postural control, although a loss of vision can be compensated by other sensory modalities(20, 22). In order to achieve information of the orientation of the body in space, the CNS also receive sensory inputs from proprioceptive, cutaneous, and joint receptors of the somatosensory system(20). Proprioceptors provide inputs regarding the configuration of the head and extremities, and their position in respect to the trunk(22). The vestibular system inform the CNS regarding movement of the head(25). This information may elicit reflexes and changes in the control of axial and appendicular muscles that contribute to the postural control(26).

2.2.2 Muscle and skeletal system

The task of stance postural control has stringent stability demands, requiring the CoM to be kept inside the relatively narrow limits of the BoS of the feet*(20)*. The alignment of the body segments determines to a great extent the energy used to keep a standing position(22). A standing position is normally maintained by a vertical alignment of the body segments, but can also be maintained when bending forward or sideways(20), but more muscular effort is required if the CoM moves outside the BoS(20). This vertical alignment of the body segments requires, among other, a functional skeleton, adequate range of motion in the joints, and a sufficient muscle tone. The muscle tone is the force with which a muscle resist being lengthened. A certain level of muscle tone is present in a normal, conscious and relaxed person, and prevent the body from collapsing in response to the pull of gravity(20). During stance, the muscle tone in certain antigravity muscles, such as the thoracic erector spinae, the iliopsoas, the tibialis anterior, the soleus and gastrocnemius increases (20). This represent the postural tone, which helps to maintain a relaxed standing body posture with minimally increased energy costs(27). The postural tone is influenced by e.g. the somatosensory, visual and vestibular systems(20), which emphasize the complexity of the postural control.

When standing still, small amounts of spontaneous sway can be observed(20). This postural sway include changes in trunk inclination, location of the CoM, etc.(22) The visual, vestibular and somatosensory systems affect the postural sway, and an increase in postural sway is observed when compromising one of these(22). However, some studies indicate that it would be too simplistic to equate increased postural sway and poor postural stabilisation(20, 22). The origins and the role of postural sway is not known, even though different theories exist(22).

2.2.3 Other physical mechanisms contributing to the postural control

Several strategies are used to maintain postural control during stance. The nervous system combines independent muscles into units called muscle synergies*(20, 28)*. Those groups of muscles, activated in synchrony or with fixed time delays, can be used by the nervous system as building blocks for constructing motor output patterns during different tasks(28). A broad range of responses is used to maintain postural control. Some of them, like the ankle and hip strategies, are thought to result from the activation of independent muscle synergies(28). The ankle strategy is a mechanism used for restoring the CoM to a position of stability. When exposed to a perturbation, the sway of the subject will induce a body movement centred primarily in the ankle joints. The muscles activated in the legs and truncus will be recruited in a specific order, the distal muscle prior to the proximal muscles, keeping the subject from falling over. (20). A similar pattern of muscle activation that takes place mainly in the upper legs and truncus, is called the hip strategy(20). A person can also jump or take a step to recover stability. This stepping strategy moves the CoM inside the borders of the BOS, or gives the CoM a more appropriate localisation within the borders of the BoS(20). Different combinations of these and other strategies are often used to maintain postural stability(20).

Reactive postural adjustments and anticipatory postural adjustments (APAs) and are strategies contributing to postural control during the performance of voluntary movements(22, 29). The reactive postural adjustments counteract disturbances to the postural stability using sensory feedback, thus restoring postural stability after a perturbation(29). APAs are pre-emptive muscle activity occurring prior to expected perturbations to the body(30), for instance activation of the postural muscles of the lower limbs and trunk in advance of a voluntary arm movement(31). They can be measured up to 100-150 Ms prior to the first activity of the focal/ actual action, and produce shifts in the size and position of the CoP(22). This type of postural control is thought to reduce the effects of forthcoming perturbations on the body, and the

ability to generate adequate APAs is considered of the greatest importance in a broad range of daily activities (31).

2.3 Postural control in individuals with CP

Deficits in the control of posture is an important aspect of CP, as defined by SCPE(8), and children with CP often exhibit activity limitations that are associated with postural control problems(19, 22, 32). The upper motor neuron syndrome characterizing CP includes impaired selective motor control, and altered sensory feedback, spasticity, increased tendon reflexes and muscular fatigue(33), factors that may contribute to decreased postural control. The muscular fatigue is known to lead to diminished effectiveness in sensory inputs and motor output of postural control(34). The extent of the problems varies with the degree of disability in the child(22). Many children prefer sitting rather than standing, due to the relatively large and stable BoS and the location of the CoM closer to the ground(22). The following will focus on postural control in standing.

2.3.1 Postural control during quiet stance

Changes in body alignment are often seen in children with CP, and may increase the effort required to stand still(22). Factors contributing to abnormal alignment of the body may be reduced range of motion in joins, typically the ankle, knee and hip, and contractures close to the same joints(22). These constraints may lead to abnormal positioning of the body segments and a crouched posture during stance(22). Muscle weakness can also contribute to an abnormal body alignment, as in children with unilateral spastic CP where a displacement of the CoP towards the least affected side can be observed(22).

The postural sway differ also somewhat between individuals with CP and TD. Studies have shown increased displacement of CoP during quiet stance in individuals with CP versus typically developing (TD) children(22). Based on this observation, some researchers have come to the conclusion that individuals with CP have an increased postural sway(22). However, not all children with CP have increased postural sway during stance(35).

2.3.2 Postural adjustments to perturbations

Individuals with CP show a decreased ability to recover stability after a perturbation. Studies have shown that it takes children with CP longer to recover stability, when standing on a moving platform, and they show a greater displacement of CoP(32) (23).

The neuromuscular response that contribute to stability recovery when exposed to perturbations show specific constrains in individuals with CP(32). This applies particular to the recruiting and timing of muscle responses when compared to TD individuals: Studies on both individuals with spastic diplegia and spastic hemiplegia show that there is an inappropriate co-contraction of agonist and antagonist muscles, contributing to increased energy demands(36, 37). The response sequencing is also inappropriate with a more proximal to distal activation, i.e. the onset of contractions in the ankle muscles are delayed, while the thigh muscles contracts early(36, 37). Also individuals with ataxia show delays in the onset of ankle muscle responses, but they do not show the muscle response reversals(22).

Research indicates that the posture and alignment of individuals with CP is one factor contributing to the disorganized muscle responses(38). When TD children were asked to mimic the crouched posture seen in individuals with CP, they showed 1) more energy-inefficient coactivation of agonists and antagonists, and 2) more proximal-to-distal muscle response timing(36, 38). Another factor observed in individuals with CP is the poor ability to increase muscle response amplitude when balance threats increase in magnitude(39).

Problems in initiating adequate anticipatory postural adjustments (APA) is observed in both individuals with unilateral(22) and bilateral spastic CP(31). This includes a delay in the timing of the APAs, the activation magnitude is too small(31), and one study did even find a total lack of APAs(22).

2.3.3 Sensory deficits contributing to postural control problems in individuals with CP

Children with CP are more susceptible to lost balance during sensory changes than subjects with typical development(24). Children with spastic and bilateral diplegic CP depend more than TD children on visual stimuli to maintain balance control(24, 40). Lidbeck et al(40). propose that the deficits in sensory processing may be a major contributor to the difficulties keeping an erect posture(40), but it may also arise from delayed muscle activation(24). Proprioceptive information is also shown to be an important regulatory mechanism of postural control in children with CP(24). Recently there has also been an increased attention to the role of the vestibular function in the development of motor control in children with CP(41).

2.4 Tools for measuring postural control in individuals with CP

There is a lack of adequate tools for assessing postural control in individuals with CP, and there is limited documentation of the measurement properties of the existing tools. Several interventions are proposed to improve postural control in individuals with CP, these include: trunk targeted training, hippotherapy, horseback riding, constraint-induced therapy, electrical stimulation, virtual reality training, adaptive seating and training on a moving platform(42, 43). However, the lack of adequate assessment tools results in difficulties knowing which interventions that are most appropriate for improving postural control(42).

Among the methods used to investigate postural control children with CP in research, force platforms are the most frequently used tool, measuring the trajectory or other properties of the CoP (23). Electromyography, infrared emitter, kinematic analysis and head movements is more seldom used for investigating postural control in children with CP, whereas there is a lack of studies using scales and functional tests(23).

There is no consensus on how postural control should be assessed in individuals with CP in the clinical setting(43), and several clinical tools is required in the assessment of postural control, due to the complexity of this construct(43). Saether et al examined the measurement properties of 22 clinical balance tools intended for individuals with CP, measuring different aspects of postural control and motor function. Among the tools assessing balance when standing, the Timed Up and Go and Timed One-Leg Stance were the measurement tools with the best level of evidence(43). However, they highlight the need for further studies in order to provide more levels of evidence regarding the reliability and responsiveness of the tools(43). Thus, there is still a lack of clinical tools with good measurement properties that assess the ability to maintain balance when standing(43). I will in the next paragraph discuss the concept measurement properties.

3. Measurement properties of assessment tools

Confidence in the data provided by measurement tools is a prerequisite when using them for assessment in clinical research and decision making(44). The data provided should be accurate and meaningful indicators of the trait that the tool is intended to measure(44). Two important prerequisites regarding the measurement properties are good validity and good reliability(44). Validity is defined by the COSMIN panel as the degree to which an instrument measures the construct(s) it purports to measure(45). Reliability is defined by the COSMIN panel as the degree to which a measurement is free from measurement error(45). Reliability is the extent to which scores for patients supplied by a measurement tool, who have not changed, are the same for repeated measurements(45).

Reliability can be expressed as a ratio of the true score variance to the total variance: (44, 46)

$$Reliability\ index = \frac{True\ score\ variance}{True\ score\ variance + error\ variance}$$

Thus, perfect reliability (zero error), as seen when the observed score is the true score, gives a coefficient of 1.00. As error increases, the ratio will approach zero. For many clinical measurements, reliability should exceed 0.90 to ensure reasonable reliability(44). There are no standard values for acceptable reliability, therefore the researcher must determine «how much» reliability is needed to justify the use of a particular tool(44).

Different types of reliability exist, among them test-retest reliability. Test-retest reliability assessment is used to determine that an instrument is capable of measuring a trait with consistency(44). A test-retest study explores the variation in measurements taken by an instrument when applied on the same subject(s) on several occasions, under the same conditions(46). The interclass correlation coefficient (ICC) is the preferred index when analysing test-retest reliability(44).

4. Computer-based video analysis

A computer-based video analysis software, hereafter named video software, has previously been developed by the Max/ MSP/ Jitter environment for analysing musical gestures in musicians and dancers from video recordings(47). The video software has been used to quantify spontaneous movements in young infants(47) and has shown ability to predict CP in high-risk infants at 9-17 weeks post term(48). The use of this video software does not require any instrumentation or laboratory setting, only a normal 2D-video recording(49). Different variables, pictures, videos and graphs are exported from the video software, describing the movements in the video in different ways. However, this video software has not been used to assess postural control in children with CP. In our study, we therefore first wanted to explore if the computer computer-based video analysis software is able to quantify postural in individuals with CP, and if so, we wanted to examine some aspects of the measurement properties of this method.

5. Aim

The first aim of this study was to explore if variables obtained using the computer-based video analysis software could be used to assess postural control. The second aim of this student thesis was to explore the test-retest reliability properties of these variables in individuals with CP and TD individuals 8-29 years of age.

6. Methods and materials

6.1 Study design and participants

In the first part of this study I explored in collaboration with medical student Marianne Jordheim Leirvik how the variables derived from a computer-based video analysis software could be used to predict postural control in subjects with CP and with TD. In the second part of the study I have explored the test-retest reliability of this computer-based video analysis.

Eligible for participation were individuals with CP and with TD, 8-29 years, who were able to understand instructions and to stand still without support for minimum 30 seconds. There were no limitations regarding CP subtype. The individuals with CP attended Beitostølen Healthsports Centre for a three week intensive training program, and took originally part in a study of the measurement properties of two clinical assessment tools of postural control in the sitting position. The participants with CP were recruited during June to November 2013. Fourteen were included in the present study. However, one individual was excluded because she was not able to stand without support for 30 seconds the day she was tested. The 24 individuals without motor impairment (the TD group) were recruited among medical students and children of employees at St. Olavs University hospital during October 2016.

Table 1

Characteristics of children with CP and TD children participating in the present study

All children				Children with CP		
	All	TD	CP	GMFCS I	GMFCS II	GMFCS III
N	37	24	13	9	3	1
Unilateral (n)	-	-	10	8	1	1
Bilateral (n)	-	-	3	1	2	0
Male gender, n (%)	16 (43)	10 (42)	6 (46)	3 (33)	3 (100)	0
Age (years), mean (SD)	20.0 (7.2)	20.6 (6.8)	18.9 (8.0)	18.0 (7.7)	23.3 (9.8)	14
Height (cm), mean (SD)	167.4 (14.4)	170.3 (13.7)	161.8 (14.6)	159.6 (14.8)	168.8 (17.5)	161

6.2 Variables

6.2.1 Video recordings

Video recordings of the participants with CP were performed at Beitostølen Healthsports Centre in 2013, and for the participants with TD in Trondheim in October 2016. The participants were asked to stand still during three video recordings. First and second recording were of about 30 seconds, and the third recording were of about two minutes (Fig.1). In between the three recordings they had a few minutes break, with free activity.

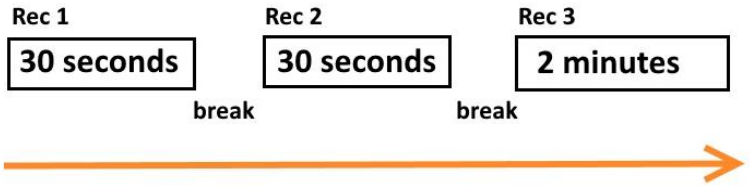

Figure 1. A timeline of the three video recordings (rec).

The assessment conditions, camera positioning, background, and lighting were the same for both groups. The recordings were obtained by a Samsung HMX F90 video camera, placed on the right side of the participants, shown in figure 2.

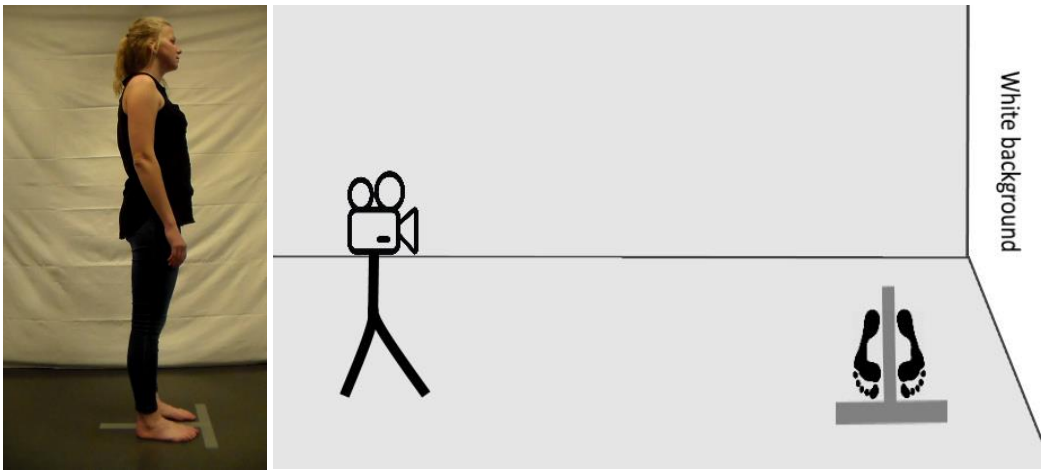

Figure 2. Illustration of the video-recording set-up.

6.2.2 Video processing and computer-based video analyses

The first and second video were trimmed to 25 seconds to exclude irrelevant movements observed at the beginning of some of the videos. These movements included turning towards the examiner to talk, scratching, and other movements that occurred because the participant did not focus on standing still in the beginning or towards the end of the recording. The irrelevant movements were excluded by removing 4 seconds in the beginning, and a few seconds towards the end. All videos in recording one and two were trimmed in order to give them the same length. The third video was not trimmed. The resolution of 1080x608 pixels was identical for all recordings.

All video recordings were assessed using the computer-based video analysis software. This software has been used in previous studies conducted by our research group(47), and is described in the background. The video recordings were used as input to the computer-based video analysis software, shown by a screenshot in Figure 4. A "motion image" that describes the movement in the video, was calculated by the software using frame differencing, the change for each pixel between two frames. The motion image is illustrated in figure 4b.

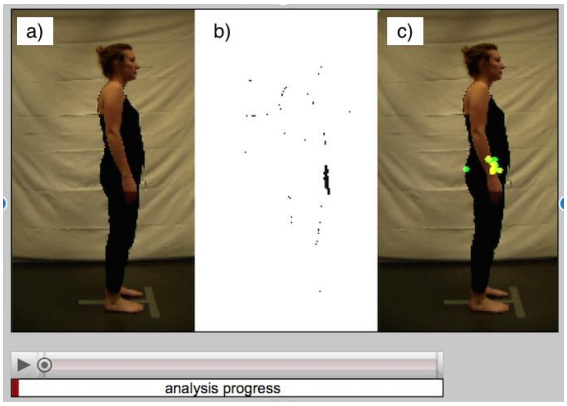

Figure 4. Screenshot of the video software. a) Input video; b) Motion image. (pixels in white indicate no movement occurred between the frames, and pixels in black represent movement) c) Illustration of the displacement of the centroid of motion.

The filtering of the motion image determines how sensitive the calculation will be for movement. In previous studies that assess spontaneous movements in young infants(50), the filtering of the motion image have been set to 0.05. In this study, there were fewer movements in the videos, as the participants were told to stand still. Hence, we needed to experiment with different filter settings to identify the optimal setting that would filter noise in the video, e.g. movements in the background and lighting, while simultaneously keeping information due to real movements in the participant. Four different filtering settings were evaluated based on observation of the motion images: 0.01, 0.02, 0.03 and 0.05. After observation of the different motion images we identified a filter setting of 0.02 as the optimal filter setting for our use (Fig 5).

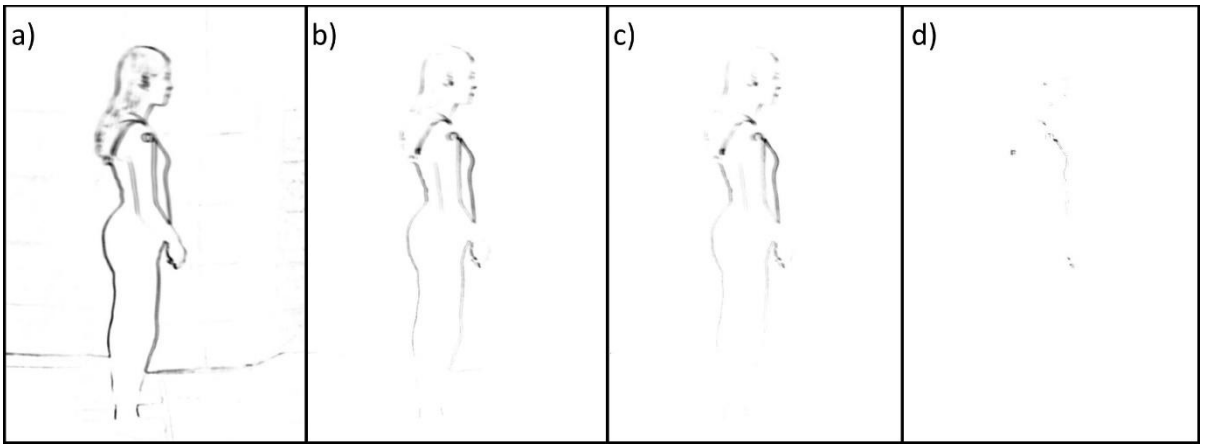

Figure 5. Illustration of four different filter settings in the motion image. a) 0,01; b) 0,02. (the one chosen) We chose the filter setting 0,02 due to apparently little noise and detection of real movements in the participants; c) 0,03; d) 0,05.

6.2.3 Variables provided by the video software

Several variables that describe the different aspects of the movement in the video recording are derived from the motion image.

One variable is the quantity of motion (QoM), defined as the total amount of active, or changing pixels from one frame to the next, divided by the total number of pixels(51). If the QoM is 1, this means that all the pixels have changed from one frame to the next, and if there is no movement at all, it will be 0. The QoM can be illustrated as seen in figure 6.

Figure 6. An illustration of the variability of quantity of motion throughout the video recording. The white areas represent no motion, while the black areas represent the pixels that have changed the most for this individual through the recording. In this example, the broad black lines represent a bigger amount of movement and the missing contour of the feet illustrate that little motion has been present.

The centroid of motion is another variable. It is defined as the spatial centre of all the active pixels in the motion image and can be calculated for horizontal (x) and vertical (y) directions. The centroid of motion in the horizontal plane may be seen as a correlate to the centre point of all horizontal movements in the video recording(47), reflecting the postural horizontal sway when standing still. The position of the centroid of motion is illustrated in figure 7. The mean of the centroid of motion in horizontal direction was quantified as Cx_{mean}, and describes the average location of the centroid of motion in the horizontal axis in the video picture during the entire video sequence. The Cx_{sd} describes the variability of the centroid in the horizontal axis during the video sequence. The Cx_{sd} will thus rely less on where the person is located in the picture.

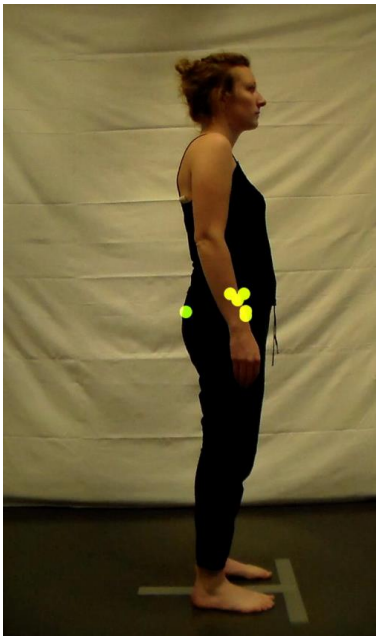

Figure 7. Illustration of the displacement of the centroid of motion for a short video clip. The dots are an expression of the displacement of the centroid of motion for the frames through the clip.

6.2.4 Diagnosis and classification of CP

Cerebral palsy was diagnosed in line with the criteria and classification proposed by the SCPE(8). Gross motor function was classified using the GMFCS(9).

6.3 Statistics

Data derived from the video recordings were analysed using Matlab version 2015a and SPSS version 24.0. (SPSS Inc, Chicago IL, USA). In order to correct for between-subject differences in body size, the variables were divided with the height of the subjects measured in pixels in the video recording. To make interpretation easier, we scaled all the variables by multiplying them with 100.000.

Komogorov-Smirnov test indicated that some variables were normally distributed, while others were not. Nonetheless we used parametric statistics to compare groups (52), and location and variability of the data were described as mean and standard deviation (SD). Relative reliability of Cx_{mean} and Cx_{sd} was assessed by calculating interclass correlation coefficient (ICC) and 95 % confident intervals (CI), using models ICC 1,1 and 3,1. In model one(one-way random effects) all within-subject variability is assumed to be error of measurement. In model 3 (two-way mixed effects) the effect of any systematic shift is not considered part of the error of measurement(53). When no systematic error is present, ICC [1,1] is similar to ICC [3,1](53). Therefore, both models were used in order to reveal any potential systematic errors. As proposed by Portney, we defined values below 0.75 to be of poor to moderate reliability and those above 0.75 good reliability(44).

Absolute reliability was described by the standard error of measurement (SEM), which was calculated as the square root of the mean within subject variance. Low SEM expresses a small degree of measurement error(54). The smallest detectable difference (SDD) was calculated by the following formula: SEM 1.96 x $\sqrt{2}$(54). The consistency of the measurements was verified graphically using the Bland and Altman plots(55). This method plots differences between the values from two video recordings (e.g. recording one and two) against the average for these two measurements. The size, range of differences, scoring distribution, and possible measurement bias can be interpreted visually by using this method(55).

6.4 Ethics

The study was conducted in conformity of the Declaration of Helsinki. The Regional Committee for Medical Research Ethics in Northern Norway considered that ethical approval was not required according to Norwegian regulations (reference: 2013/355). Nonetheless, we obtained written informed consent from the participants and from parents.

7. Results

Three video recordings of each participant were included in the study, resulting in a total of 111 video recordings.

In the explorative part of this study we explored which of the variables calculated by the computer-based video analysis software that correlated best with postural control in the individuals with CP, assessed by the clinical measurement tool GMFM-66. The mean and standard deviation from the QoM and the centroid of motion were the variables that correlated the best. The other variables showed no significant correlations. After further analyses, the variable with the highest correlation coefficient was the Cx_{mean}. Closer observation of the data and the video recordings indicated some limitations regarding the QoM variables. These limitations included significantly higher scores for the mean value of QoM in the TD group than the CP group, whereas in the observations of the video recordings, the CP individuals had generally more movements. Moreover, the calculations of the mean value of QoM were significantly affected by differences in clothing. These limitations were much less accentuated for the centroid of motion, and we therefore decided to further explore the Cx_{mean} and Cx_{SD}. Thus, in the second part of the study I have examined the test-retest reliability of these two variables. In another student thesis, my colleague, Marianne Jordheim Leirvik has explored face and construct validity of the same variables. The mean and standard deviation as well as the mean difference with confidence intervals and p-value of Cx_{mean} and Cx_{SD} from the videos, are shown in table 2.

7.1 Relative reliability: Test-retest reliability of computer-based video analysis

The ICC values of Cx_{mean} range between 0.89 and 0.93 when we included all participants in the analyses (Table 3), indicating good test-retest reliability of the variable Cx_{mean}, according to the description of ICC values by Portney(44). The ICC value of Cx_{mean} varied between the groups, being somewhat higher in the CP group than in the TD group. The ICC values of Cx_{mean} were higher with more narrow confidence intervals when two video recordings were included, both of 30 seconds, than when also the third video recording was included. The ICC values of Cx_{mean} were identical or very close when applying ICC(1,1) and ICC(3,1) implying that no systematic error was present(53).

The ICC values of Cx_{SD} were 0.92-0.93 when all participants were included in the analyses (Table 3), suggesting good test-retest reliability. Also the ICC value of Cx_{SD} varied between the groups, it was somewhat higher in the CP group compared to the TD group. The ICC values of Cx_{SD} were higher with more narrow confidence intervals when two video recordings were included, both of 30 seconds, compared to when also the third video recording were included. The ICC values of Cx_{SD} were identical or very close when applying ICC(1,1) and ICC(3,1), implying that no systematic error was present(53).

7.2 Absolute reliability, measurement error and smallest detectable difference

The SEM values for Cx_{mean} ranged from 2.2 (4 %) to 3.1 (6 %) (Table 3), expressing a small degree of measurement error(56). The SDD values for Cx_{mean} ranged from 6.0 (10 %) to 8.5 (15 %) (Table 3), indicating that the difference between two measurements has to be at least 15 % of the Cx_{mean} value to detect a true difference. The SEM values for Cx_{SD} ranged from 0.3 (14 %) to 0.7 (27 %), and the SDD values from 0.7 (40 %) to 2.0 (76 %) (Table 3). This indicates a high degree of measurement error(54), as well as that to detect a true difference, the difference between two measurements has to be more than 40-76 % of Cx_{SD}.

7.3 Bland-Altman plots

The Bland-Altman plots for test-retest agreement of Cx_{mean} and Cx_{SD} are shown in figure 8. For all three comparisons for Cx_{mean}, a total of 34 participants (92 %) fell within two standard deviations of the mean. The Bland-Altman plot verifies graphically the consistency of the measures, as well as the slightly higher mean values for the individuals with CP. The mean difference was lowest (-0.4 (95 % CI -1.4 to 0.7)), when comparing the two 30 seconds video recordings (recording one and two), indicating higher reliability when comparing two short video recordings, compared to one short and one long recording (1.2 (CI -0.3 to 2.7) and -1.6 (CI -2.8 to -0.4)).

In the three different Bland-Altman plots for Cx_{SD}, the number of participants that fell within two standard deviations of the mean ranged between 34 (92 %) and 36 (97 %). The Bland-Altman plots for Cx_{SD} verifies graphically the consistency of the measures in TD group, while it illustrates a spread in the values in the individuals with CP. The difference between the Cx_{SD} values from the two recordings are larger in the individuals with CP than in the TD individuals, and the difference were even larger in certain individuals with CP. The plot also illustrates the significantly higher mean values of Cx_{SD} in the individuals with CP. The mean difference was slightly lower when comparing recording one and three (mean difference: 0.01; CI -0.34 to 0.32), than the two other comparisons (mean difference 0.06; CI -0.28 to 0.40 and 0.08; CI -0.16 to 0.31, respectively).

Table 2
Spatial centre of movements in the horizontal direction among 13 persons with CP aged 8-29 years, and 24 typically developing individuals aged 9-29 years.

	CP		TD		Mean diff	95% CI	p (Sig, 2-tailed)
	Mean	SD	Mean	SD			
Cx_{mean} Rec 1	62.0	9.6	55.9	7.0	6.2	0.6 to 11.8	0.032
Cx_{mean} Rec 2	63.3	9.7	55.8	5.9	7.5	1.3 to 13.8	0.021
Cx_{mean} Rec 3	61.6	8.6	54.3	6.6	7.3	2.2 to 12.5	0.007
Cx_{SD} Rec 1	5.6	2.8	1.8	0.7	3.8	2.6 to 5.0	0.001
Cx_{SD} Rec 2	5.3	2.0	1.9	0.8	3.4	2.2 to 4.6	0.001
Cx_{SD} Rec 3	5.2	1.7	2.0	1.1	3.3	2.3 to 4.2	0.001

TD = Typically developing; Rec = video recording; Cx_{mean} = mean location of centroid of motion in the horizontal axis; Cx_{SD} = centroid of motion in the horizontal axis standard deviation.

Table 3
Test-retest reliability of the computer-based video analysis between recording 1, 2 and 3 in persons with CP aged 8-29 years and typical developing individuals aged 8-29 years. In total 37 participants.

Motion image variable	Rec 1 mean (SD)	Rec 2 mean (SD)	Rec 3 mean (SD)	ICC (1,1) (95 % CI)	ICC (3,1) (95 % CI)	SEM (%)	SDD (%)
Cx_{mean} over all	58.0 (8.4)	58.4 (8.2)	56.8 (8.1)				
Rec 1-Rec 2				0.93 (0.87-0.96)	0.93 (0.87-0.96)	2.2 (4)	6.1 (11)
Rec 1, 2 and 3				0.89 (0.82-0.94)	0.89 (0.83-0.94)	2.8 (5)	7.7 (13)
Cx_{mean} CP	62.0 (9.6)	63.3 (9.7)	61.6 (8.6)				
Rec 1-Rec 2				0.95 (0.84-0.98)	0.95 (0.84-0.98)	2.3 (4)	6.3 (10)
Rec 1, 2 and 3				0.95 (0.87-0.98)	0.95 (0.87-0.98)	2.2 (4)	6.0 (10)
Cx_{mean} TD	55.9 (7.0)	55.8 (5.9)	54.3 (6.6)				
Rec 1-Rec 2				0.89 (0.77-0.95)	0.89 (0.76-0.95)	2.1 (4)	5.9 (11)
Rec 1, 2 and 3				0.79 (0.63-0.89)	0.79 (0.64-0.90)	3.1 (6)	8.5 (15)

ICC = interclass correlation coefficients; Cx_{mean} = mean location of centroid of motion in the horizontal axis; Rec = video recording; SEM = standard error of measurement; SDD = smallest detectable difference; IQR = interquartile range; TD = typically developing individuals.

Table 4
Test-retest reliability of the computer-based video analysis between recording 1, 2 and 3 in persons with CP aged 8-
and typical developing individuals aged 8-29 years. In total 37 participants.

Motion image variable	Rec 1 mean (SD)	Rec 2 mean (SD)	Rec 3 mean (SD)	ICC (1,1) (95 % CI)	ICC (3,1) (95 % CI)	SEM (%)	SDD (%)
Cx_{SD} over all	2.1 (2.5)	3.1 (2.1)	3.1 (2.1)				
Rec 1-Rec 2				0.93 (0.87-0.96)	0.93 (0.87-0.96)	0.7 (27)	2.0 (76)
Rec 1, 2 and 3				0.92 (0.86-0.95)	0.92 (0.86-0.95)	0.6 (23)	1.8 (64)
Cx_{SD} CP	5.6 (2.8)	5.3 (2.0)	5.2 (1.7)				
Rec 1-Rec 2				0.95 (0.84-0.98)	0.95 (0.84-0.98)	1.1 (21)	3.2 (58)
Rec 1, 2 and 3				0.82 (0.60-0.93)	0.80 (0.58-0.93)	1.0 (18)	2.6 (49)
Cx_{SD} TD	1.8 (0.7)	1.9 (0.8)	2.0 (1.1)				
Rec 1-Rec 2				0.89 (0.77-0.95)	0.89 (0.76-0.95)	0.3 (14)	0.7 (40)
Rec 1, 2 and 3				0.83 (0.69-0.91)	0.83 (0.70-0.92)	0.4 (20)	1.0 (54)

ICC = interclass correlation coefficients; Cx_{SD} = centroid of motion in the horizontal axis standard deviation; Rec = video recording; SEM = standard error of measurement; SDD = smallest detectable difference; IQR = interquartile range; TD = typically developing individuals.

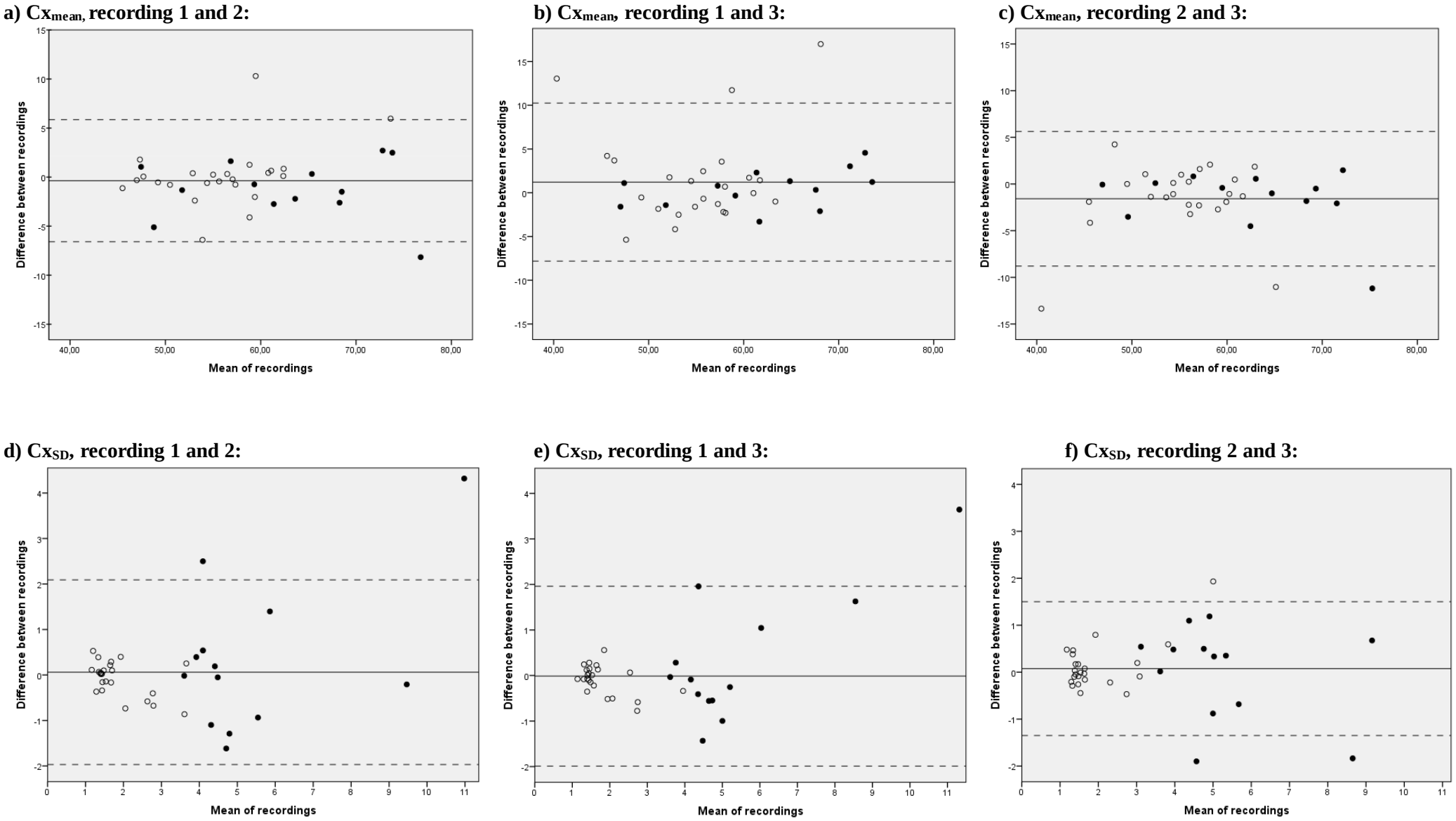

Fig. 8: Bland-Altman plots of difference against the average of Cx_{mean} and Cx_{SD} of 37 persons measured three times, with mean difference (solid line) and ± 2SD (broken lines). a) Cx_{mean} from first and second recording. Both video recordings were of 30 seconds; b) Cx_{mean} from first (30 seconds) and third recording (2 minutes); c) Cx_{mean} from second (30 seconds) and third recording (2 minutes); d) Cx_{SD} from first and second recording; e) Cx_{SD} from first and third recording; f) Cx_{SD} from second and third recording; Black dots represent individuals with CP; white dots represent TD individuals; Cx_{SD} = centroid of motion in the horizontal axis standard deviation; Cx_{mean} = mean location of centroid of motion in the horizontal axis

8. Discussion

8.1 Main findings

In the explorative phase of this study, we found that the Cx_{mean}, which express the location of centroid of motion in the horizontal axis, correlated well with a clinical assessment of postural control in individuals with CP. The Cx_{sd}, which is the variability of the centroid of motion in the horizontal axis, did not show the same high correlations.

In the second part of the study, I found good test-retest reliability of both the Cx_{mean} and the $Cx_{sd.}$ As far as we know, these studies are the first to explore the use of computer-based video analysis in the assessment of postural control in individuals with CP.

8.2 Internal validity

8.2.1 Chance:

Regarding the test-retest reliability of Cx_{mean} and Cx_{sd}, the confidence intervals were adequately narrow, suggesting that these results were not caused by chance. This applies in particular to when all participants were included in the analyses. However, as could be expected, due to lower numbers, the ICC-values had wider confidence intervals when test-retest reliability was examined in the TD and CP group separately. Thus, the accurate ICC values in the two subgroups must be interpreted with caution.

8.2.2 Bias

All participants with CP were recruited at Beitostølen Healthsport Centre, and this population might not be representative of the total population of persons with CP, who are able to stand upright. For example, their postural control might differ from the average among their GMFCS level, or they might possess different abilities and resources compared to others with CP. However, to bias our results one has to assume that the reliability of Cx_{mean} and Cx_{sd} would be systematically different in persons with CP not recruited to the study. This assumption is rather theoretically, and we therefore do not consider it likely that our results regarding reliability are biased.

According to the COSMIN checklist, the time interval between the measurements in a reliability study depends on the construct to be measured and the target population(57). The time interval between the recordings in our study needed to be long enough to let the participant recover if he or she felt tired after the recording, but so short that the postural

control did not change between the recordings. The learning potential during the video recordings were considered minimal. Based on this, we considered a few minutes break sufficient to assess test-retest reliability in this pilot study.

8.2.3 Confounding

Several factors regarding the video recordings and participants could influence on the results. The individuals with CP and the TD individuals both represent a heterogenous population regarding their age and gender, but the distribution of these two variables was similar in the two groups, and they are therefore unlikely to have confounded the results of this study. We believe that the use of TD individuals as controls is a strenght of the study.

The recordings of the individuals with CP and TD individuals were recorded at different locations, at different times, and with different examiners. However, when recording the TD individuals, we tried our best to copy the setup from the recordings of the CP group, including the use of the same videorecorder that was used at Beitostølen Healthsports Centre. Most importantly, the camera positioning, the lightning conditions, the clothing and the placement of the participants during the all three recordings were the same for each participant, and therefore differences in the setup is not likely to have confounded the results of the reliability analyses.

The length of the different video recordings might affect the result, a factor that would be eliminated when comparing the two videos of the same length. When looking at all participants, the ICC value and the confidence intervals were quite similar when including the two 30 seconds video recordings as when including also the third video recording of two minutes (Table 3 and 4), indicating that the duration of the video recordings might not affect the result. However, when looking at only the CP group or the TD group, the ICC values were lower and the confidence intervals wider when including all three video recordings, but this finding may also be due to the low number of participants in these groups. The Bland Altman plot indicates that the length of the videos did not affect the Cx_{SD} value, as the mean difference was the lowest when comparing one 30 second recording and one two minutes recording(Fig.8). However, the mean difference for Cxmean was the lowest when comparing the two 30 seconds recording, indicating that this variable might be affected by the duration of the recordings.

The lightening conditions and the clothes are other possible confounders. However, general linear model analyses showed that these factors did not affect the values of Cx_{mean} and Cx_{sd} essentially (data not shown). As the clothes and lightening conditions were the same for all recordings of each participant, this would anyway not have affected the reliability analyses.

The centroid of motion is likely to be affected by postural movements as well as several other movements in the video picture. If a person stand almost still, just swaying a little, the spatial center of the active pictures will fall in the lower part of the trunk (Fig.7). As we placed the participants in the middle of video picture, this point (the centroid of motion), would typically fall in the middle of the video picture. If this person sway forward by bending in the ankles, then the centroid of motion would still lie within the lower part of the trunk of this person, but the point is now more to the right in the picture (Fig.7), increasing the value of the centroid of motion in the horizontal axis. If the person bend forward by flexing the hip, the centroid of motion will move both to the right and a bit up in the video picture, thus increasing the value of the centroid of motion both in the horizontal and vertical axis. Also movements of the arms will change the location of the centroid of motion, and moving the arms to maintain stability will therefore also influence the values of the centroid of motion. Thus, postural movements in the anteroposterior direction, will cause the centroid to move to the left or right in the video picture, and change the values in the horizontal and vertical direction.

However, also movements irrelevant of postural control would change the location of the centroid of motion, and this was observed in several of the video recordings included in the study. Talking and facial expressions would cause the centroid of motion to locate closer to the face, and movement of the fingers and hands would move the centroid of motion closer to the hands. These occational movements would be expected to reduce reliability, since they are unlikely to be exactly repeated during two different video recordings. Also movements in the background of the participant could affect the location of the centroid of motion, but the setup with white background made this less likely. Movements in the mediolateral direction would not be counted by the centroid of motion, but rotational movements might. Characteristics in the posture of a participant (e.g. leaning forward, leaning bacward, deformities or a crouched posture) might also affect the location of the centroid of motion. The values of the centroid of motion gives no information of where in the body the movements are. Thus, the location and values of the centroid of motion is calculated based on some of the movements related to the postural control, and some movements irrelevant of the postural control in the participants.

8.3 Comparison with the literature

As our study is the first that explore the possibility to assess postural control in individuals with CP using this computer-based video analysis software, there is limited published literature for comparison. However, Adde et al(47) have in previous studies showed that the variables best suited to predict CP in preterm infants included the standard deviation of the centroid of motion and the mean and standard deviation of the QoM. In this studies a combined variable (CPP), was calculated based on these three variables, and that variable was the most accurate in predicting CP(47). However, while they studied spontaneous movements of the infant, we have compared our analyses with postural control assessed in the standing position, and this may explain the better correlation with Cxmean. If we had been able to clinically measure postural sway, it may be possible that these measures would have correlated better with Cx_{mean} and $Cx_{SD.}$

8.4 Interpretation

8.4.1 Explorative phase

In the explorative part of this study, we found that the variable that correlated best with a clinical assessment of postural control (assessed by using GMFM-66) in individuals with CP was the centroid of motion in the horizontal plane. The QoM was excluded from further analyses, because it seemed to fragile regarding confounders and values difficult to interpret, even though this was the variable we predicted in advance to be best qualified. The centroid of motion was the most robust variable, depending less on the clothing of the participants. The correlations with the clinical assessment of the postural control in the individuals with CP were good for Cx_{mean}, and low for Cx_{SD}.

8.4.2 The variable Cx_{mean}

The Cx_{mean} was the variable that showed the best correlations with the clinical assessment of postural control in the individuals with CP. This variable did also show good test-retest reliability. However, this variable shows the average location of the centroid of motion in the horizontal axis. A high value does not equal more or less movements, instead it implies that the mean location of the centroid of motion is to the right in the video picture. A low value of Cx_{mean} indicates that the mean location of the centroid of motion is to the left in the picture. Therefore, the Cx_{mean} may be an indicator of posture and alignment of the body segments, such as a crouched posture, which are important aspects of postural control. Also irrelevant movements, such as talking and moving the fingers, could affect the Cx_{mean} value.

The good test-retest reliability of Cx_{mean} shown by the high ICC-values and the associated narrow confidence intervals, was supported by the low SEM values and the low SDD values (Table 3), indicating a small degree of measurement error and that the difference between to measurements of the same subject has to exceed 15 % to detect a true difference. Also the Bland-Altman plots strengthens the good reliability.

8.4.3 The variable Cx_{SD}

The Cx_{SD} is the variability of the centroid of motion. The correlations with postural control was found to be low for this variable. The test-retest reliability of this variable was good, but the Bland-Altman plot illustrate less consistency of the measures in some of the individuals with CP (Fig 8). In contrast to Cx_{mean}, this variable is indicative of the size of the displacement of the centroid of motion through the video recording, and thus it depends less on the posture and placement of the participant in the video picture. Thus, it might be concluded that the Cx_{SD} is more suitable to predict postural movements. Irrelevant movements might also affect the Cx_{SD} value, and the reliability of Cx_{SD} might be affected if this movement pattern differ in the three recordings.

The ICC values and associated confidence intervals for Cx_{SD} indicated good test-retest reliability. However, the high SEM values (14-27 %), describing the random component of measurement error, indicated poor absolute reliabiliy and a high degree of measurement error(54). The SDD values (40-76 %) imply that, to detect a true difference, the difference between two measurements from the same subject has to be more than 40-76 % of Cx_{SD}. Irrelevant movements, which are likely to differ in repeated recordings of the same person, might have contributed to these numbers. Anyway, this indicates that the Cx_{SD} was less suitable to measure postural control in out study. The Bland-Altman plots illustrates less consistency of measures in individuals with increased mean values of Cx_{SD}, compared to individuals with low mean values of Cx_{SD}.

8.5 Implications in future research

I believe that the computer-based video analysis software, if further explored, may be used to assess postural control in individuals with CP.

Most importantly, in future research the reliability of this method should be investigated in a larger population of individuals with CP with more diversity regarding gross motor function. The COSMIN checklist for assessment of the quality of studies suggest that at least 50 participants should be included(58), and moreover that the whole spectrum of the population is included. In our case, the latter means a larger proportion of participants with GMFCS levels II and III, than in our study. A standard procedure should be described for the setup, clothing and the recordings of the videos, to minimize the effects of potential confounders.

GMFM-66, the clinical measurement tool that was used as the reference method in the validity analyses, evaluates the performance of different physical activities related to postural control in the standing position. However, GMFM-66 do not specifically measure postural sway or postural control in quiet stance. Therefore, it will be interesting to choose other reference methods than the one we used, as we suspect the computer-based video analysis to be sensitive to postural sway and postural control during quiet stance. One such appropriate tool is force platforms, used in research but not in the clinic. This tool is used track the displacement of the CoP, and thus to calculate postural sway. I hypothesize that postural control assessed with a force platform would be better correlated with QoM and Cx_{SD}, than with Cx_{mean}, and consequently that these two variables may better indicate other aspects of postural control.

The duration of the video recordings should be investigated further, to reveal the impact on the reliability, and to determine if the videos recorded should be short or long. The reliability should also be assessed when videos are recorded with a wider break, e.g. one day between the recordings. The chosen filtering setting was believed to be the best suited in our study. However, this setting may not be the best suited in other conditions, and should be reevaluated in future studies.

As we believe that the variables QoM and the Cx_{SD} may have the potential to be used to assess postural control during quiet stance, I think these variables should be further explored. The Cx_{mean} should be further explored, as it has the potential to be used for assessment of certain aspects of postural control. There is also a possibility that some of the other variables calculated by the computer-based video analysis software, that are not mentioned in my thesis, may have potential to quantify postural control.

8.6 Clinical implications

There are several advantages of using the computer-based video analysis software for the assessment of postural control in individuals with CP. The use of a video camera and a computer-based video analysis software makes this method objective, and thus reduces the risk for both systematic and random errors that may be more likely in subjective methods. The video recordings in this study appeared to be easy to perform. The process demand only simple video recording equipment and the computer software. The method is cost-effective, it inflict minimal discomfort to the participant tested, and can be carried out quickly. This makes the method applicable in a clinical context, as well as reproducible in studies regarding i.e. the responsiveness of the method.

9. Conclusion

We found that the variable Cx_{mean} from the computer-based video analysis software describes certain aspects of postural control in individuals with CP, 8-29 years. The test-retest reliability of this variable is good. However, more studies are required to further evaluate this method and to explore if other variables of the computer-based video analysis may better describe other aspects of postural control.

10. Acknowledgements

Writing this thesis would not have been possible without the support and guidance that I received from many people.

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