Physiotherapy Theory and Practice, Early Online:1–7, 2013

ISSN: 0959-3985 print/1532-5040 online
DOI: 10.3109/09593985.2012.757404

REPORT

Identification of fidgety movements and prediction of CP by the use of computer-based video analysis is more accurate when based on two video recordings

Lars Adde, PhD, PT[1,2], Jorunn Helbostad, PhD, PT[2,3], Alexander R. Jensenius, PhD[4], Mette Langaas, PhD[5] and Ragnhild Støen, MD[1,6]

[1]*Department of Laboratory Medicine, Children's and Women's Health, Norwegian University of Science and Technology, Trondheim, Norway*

[2]*Department of Clinical Services, Physiotherapy Section, St. Olav University Hospital, Trondheim, Norway*

[3]*Department of Neuroscience, Norwegian University of Science and Technology, Trondheim, Norway*

[4]*Department of Musicology, University of Oslo, Oslo, Norway*

[5]*Department of Mathematical Sciences, Norwegian University of Science and Technology, Trondheim, Norway*

[6]*Department of Pediatrics, St. Olav University Hospital, Trondheim, Norway*

ABSTRACT

This study evaluates the role of postterm age at assessment and the use of one or two video recordings for the detection of fidgety movements (FMs) and prediction of cerebral palsy (CP) using computer vision software. Recordings between 9 and 17 weeks postterm age from 52 preterm and term infants (24 boys, 28 girls; 26 born preterm) were used. Recordings were analyzed using computer vision software. Movement variables, derived from differences between subsequent video frames, were used for quantitative analysis. Sensitivities, specificities, and area under curve were estimated for the first and second recording, or a mean of both. FMs were classified based on the Prechtl approach of general movement assessment. CP status was reported at 2 years. Nine children developed CP of whom all recordings had absent FMs. The mean variability of the centroid of motion (C_{SD}) from two recordings was more accurate than using only one recording, and identified all children who were diagnosed with CP at 2 years. Age at assessment did not influence the detection of FMs or prediction of CP. The accuracy of computer vision techniques in identifying FMs and predicting CP based on two recordings should be confirmed in future studies.

INTRODUCTION

Observation and assessment of the quality of spontaneous movements in young infants, the so-called general movements (GMs), has arisen as a reliable and valid method for the prediction of severe neurological impairments such as cerebral palsy (CP; Adde et al, 2007; Bruggink et al, 2009a; Burger, Frieg, and Louw, 2011; Prechtl et al, 1997). Normal GMs occur in age-specific patterns and between 9 and 20 weeks postterm age are characterized by small movements of moderate speed and variable accelerations of the neck, trunk, and limbs in all directions. These movements are called fidgety movements (FMs), and the absence of FMs during 9–20 weeks postterm age is highly predictive for the development of CP (Einspieler and Prechtl, 2005; Prechtl et al, 1997).

Site and severity of brain lesions and cerebellar transverse diameter seen on early magnetic resonance imaging (MRI) have been shown to be associated with absent FMs (Ferrari et al, 2011; Spittle et al, 2010). Observation and classification of FMs require highly experienced and skilled observers (Adde et al,

Accepted for publication 18 November 2012

Address correspondence to Lars Adde, PhD, PT, Department of Laboratory Medicine, Children's and Women's Health, Norwegian University of Science and Technology, Olav Kyrresgt. 11, 7491 Trondheim, Norway. E-mail: lars.adde@tnu.no

2009), and thus, a computer-based video analysis tool has been presented as a technique for qualitative and quantitative assessment of GMs in young infants (Adde et al, 2009, 2010). The customized General Movement Toolbox (GMT) has been designed to extract various quantitative movement features from a regular video recording (Adde et al, 2009, 2010). The GMT software program thus makes it possible to study movement features assumed to be essential elements of FMs. Using one video recording performed during the FM period, the GMT has been shown to identify FM in young infants with a sensitivity of 81.5% and a specificity of 70% (Adde et al, 2009) and to predict CP at 5 years of age with a sensitivity of 85% and a specificity of 88% (Adde et al, 2010).

The method of GMs assessment suggests that it is necessary to use at least one video recording from the FM period (9–20 weeks postterm age) and a second video recording if FMs are not identified on the first recording (Einspieler et al, 2004). Previous studies on the use of the GMT to identify FMs have not considered the number of recordings per infant or age at the time of recording(s), as long as it happened within the age window defined as the FM period (Adde et al, 2009, 2010). Thus, it is not known whether there is a maturational change in the movement variables derived by the GMT software with increasing age of the infant within the FM period. The intensity of infant movements might also differ in different video recordings, and more than one recording might be necessary to capture representative patterns of an infant's movement variation.

The aim of the present study was to determine the influence of postterm age at assessment on sensitivities and specificities for FMs and CP at 2 years, and whether using the mean of two video recordings improves the accuracy of the computer-based detection of FMs and prediction of later CP.

METHODS

Participants and time of assessment

Infants were recruited from two previous studies on GMA and computer-based video analysis (Adde et al, 2007, 2009) if they had at least two video recordings taken during the FMs period. Video recordings from 53 infants were available, and one child was excluded due to uncertain CP status at 2 years of age. The study group thus consisted of 52 infants; 19 normal term or near-term born infants recruited from the maternity ward and 33 infants recruited from the Neonatal Intensive Care Unit (NICU). The group from the NICU consisted of infants with different risk profiles for adverse neurodevelopment. Eight infants were extremely preterm (born with a gestational age (GA) <28 weeks and/or birth weight (BW) <1000 g); and 10 infants with a GA >28 and a BW >1000 g had diagnosis indicating high risk of adverse development including arterial ischemic stroke (AIT), moderate hypoxic-ischemic encephalopathy (HIE), protracted hypoglycemia combined with *E. coli* sepsis or abnormalities on cerebral imaging (periventricular leucomalacia, intraventricular hemorrhage, hydrocephalus). The 15 remaining NICU infants had diagnosis indicating low-to-intermediate risk of adverse development (mild HIE, moderate preterm birth with normal cerebral imaging).

Age on assessment was corrected for GA according to prenatal ultrasound for all infants. Two infants had more than two recordings, and the two recordings closest in time were chosen. Median postterm age on recording was 11 weeks (range 9–14) and 14 weeks (range 13–17) at the first and second recordings, respectively. Figure 1 shows the distribution of the first and second recordings according to the infants' age.

All parents gave written informed consent, and the Regional Committee for Medical Research Ethics and the Norwegian Social Science Data Services approved the study.

Video recordings

Two or more video recordings were performed according to Prechtl's method for GM observation (Einspieler and Prechtl, 2005; Einspieler et al, 2004). Recordings were taken with the infant lying in a supine position with a standard data acquisition

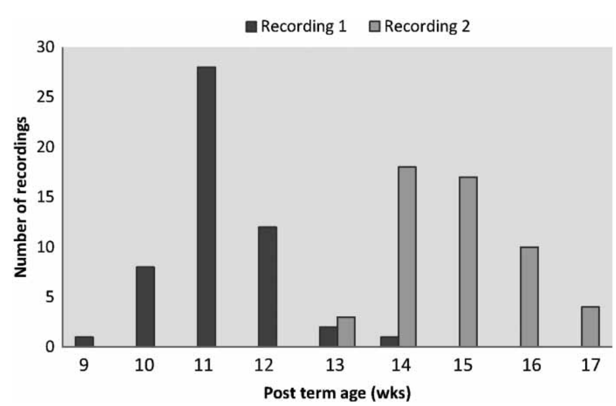

FIGURE 1 Postterm age of infants at the time of recordings.

set-up using a stationary overhead digital video camera (Sony DCR-PC100E). The infants were awake, active, and wearing a diaper and a bodysuit. Subsequently, the video recordings were edited into sequences where the infants were awake, active, and comfortable for later GM observation and classification according to Einspieler et al (1997, 2004). Additional editing was done to remove movements in the video not generated by the infant (e.g., parents, examiner), and sequences of 50 sec to 5 min duration were created.

General movements

The classification of FMs was done by a trained GM observer (LA) according to Prechtl‘s method (Einspieler et al, 2004). FMs were classified as normal if they were present (F++ if continuous, F+ if intermittent, or F+/− if sporadic), or abnormal if they were absent (F−) or abnormal in nature (Fa; i.e., with excessive amplitude, speed, and jerkiness).

General movement toolbox (GMT)

The GMT has been described elsewhere (Adde et al, 2009, 2010). A screenshot of the computer software is shown in Figure 2. The original video is the basis for the calculation of a motion image, by subtracting subsequent frames in the video stream. Black pixels in the motion image indicate no movement between the video frames, and white pixels represent movement. Pre-processing and filtering of the motion image have been described previously (Adde et al, 2009). The GMT performs movement feature extraction based on the filtered motion image, and the resultant data are exported for statistical analysis.

The movement variables chosen for this study are the variables shown previously to be significant for the detection of FMs and prediction of CP (Adde et al, 2009, 2010). Quantity of motion is calculated as the sum of all active pixels (white) in the motion image, where a value of 0 would mean no movement and 1 would be movement in all parts of the image. Variables derived and analyzed from the quantity of motion, are the mean (Q_{mean}) and standard deviation (Q_{SD}) of the quantity of motion. The centroid of motion is the spatial center of all the changing pixels in the motion image and can be considered the center point of all movements in the image. The variability of the centroid of motion is quantified as the standard deviation (C_{SD}). Finally, a fourth variable, the CP Predictor (CPP), was quantified from the combination of three variables: (1) the centroid of motion standard deviation; (2) the quantity of motion mean; and (3) the quantity of motion standard deviation and has been shown previously to be the best predictor of later CP (Adde et al, 2010).

Neurodevelopmental outcome at 2 years of age

All high-risk infants underwent multidisciplinary assessments at St. Olavs University Hospital at 3, 9, 15, and 24 months corrected age (Adde et al, 2007). A consultant in neonatology (RS) did neurological examination of all high-risk children. CP was diagnosed according to the European classification system of CP at 2 years of age (Cans, 2000). For all low-risk infants, information regarding CP status was obtained from the family physician. To further improve the identification of children with CP, parents were asked to report if they had any knowledge about a diagnosis of CP in their child or not.

FIGURE 2 Screenshot of the GMT computer software. It displays a cropped (white rectangle) input video of the infant to the left and the calculated motion image to the right. The white areas in the motion image represent movement and are the basis for the calculation of quantitative movement data.

Statistical analyses

The R environment for statistical computing was used for statistical analyses, R Development Core Team (2011) (R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/). All results presented are based on leave-one-out cross-validation. Motion image variables (C_{SD}, Q_{mean}, Q_{SD}, CPP) were used as explanatory variables in a logistic regression with present FM or CP status as response. Models using single video recordings vs. a mean of two recordings were compared. Area under the curve was calculated as a measure of the strength of the model. A classification rule was then constructed from the logistic regression. A rule can be presented as a cut-off point on the specified motion image variables, or, equivalently, as a cut-off point on probability of disease. Specificities and sensitivities can then be reported for each classification rule. By studying the ROC curves constructed from the logistic regression, we reported sensitivity and specificity for the two cut-off points 0.15 and 0.2 for the probability of disease. The cut-off points were chosen to give a balance between sensitivity and specificity and to reduce the risk of misclassifying a child with absent FMs and CP as healthy.

RESULTS

Fidgety movement classification

Eighteen recordings from nine infants were classified with absent FMs (FM−) and 86 recordings from 43 infants were classified with observable FMs (F+ +, F+ , F+ /−) by GMA. All GMA classifications were identical at assessments 1 and 2 for all infants. No infants were classified with abnormal FMs (Fa).

Cerebral palsy

Nine children had CP at follow-up. One child with CP and hemiparesis and GMFCS level III at 2 years had present FMs on both video recordings, and one child without CP at 2 years had absent FMs on both recordings. Health professionals reported neurological outcome at 24 months corrected median age (range 9–31 months) and parents reported at 26 months corrected median age (range 9–34 months). There were full consistence between health professionals and the parent's report. The only child with a follow-up as early as 9 months had definite CP. Detailed description of the nine children with CP is reported elsewhere (Adde et al, 2007).

TABLE 1 Area under curve using a single video recording vs. a mean of two recordings for GMT-derived variables for absent FMs and CP at 2 years of age.

	FM			CP		
	tp 1	tp 2	Mean	tp 1	tp 2	Mean
C_{SD}	0.83	0.82	0.90	0.82	0.81	0.88
Q_{mean}	0.68	0.69	0.77	0.64	0.54	0.68
Q_{SD}	0.62	0.61	0.71	0.55	0.53	0.60
CPP	0.74	0.78	0.87	0.74	0.77	0.85

Notes: AUC, area under curve; FMs, fidgety movements; CP, cerebral palsy; tp 1, test point 1; tp 2, test point 2; mean, mean of the two recordings; C_{SD} centroid of motion standard deviation; Q_{mean}, quantity of motion mean; Q_{SD}, quantity of motion standard deviation; CPP, cerebral palsy predictor.

Detection of FMs and prediction of CP using one or two video recordings

Area under curve values for absent FMs and CP at 2 years are shown in Table 1. There was no clear trend of first or second recording being superior in identifying absent FMs or CP at 2 years. However, two recordings were superior to one for all variables, with sensitivities with regard to CP approaching 89% and 100% for the CPP and C_{SD}, respectively, using cut-off for estimated probability of disease of 15% (Table 2). The variability of the centroid of motion (C_{SD}) and the combined variable CPP were the strongest predictors of absent FMs and, accordingly, CP at 2 years. By increasing the cut-off for estimated probability of CP from 15% to 20%, sensitivities and specificities were 78% and 79% for the CPP, respectively, and 78% and 84% for the C_{SD}, respectively.

DISCUSSION

The present study demonstrates increased accuracy of computer-based video analysis in identifying infants with absent FMs and CP at 2 years when using two instead of one recording from the FM period. All infants who developed CP at 2 years of age could be identified at 9–17 weeks postterm by using the mean centroid of motion (C_{SD}) from two video recordings. Recording age (early vs. late in the FM period) did not seem to influence the accuracy of the method in predicting CP when using only one recording. To our knowledge, this is the first study to assess the

TABLE 2 Sensitivity and specificity of GMT-derived movement variables for absent FMs and CP at 2 years using a single video recording vs. a mean of two recordings. The estimated predicted probability of absent FMs and CP was selected for at least 15% or more.

	FM						CP					
	Sensitivity			Specificity			Sensitivity			Specificity		
	tp 1	tp 2	Mean	tp 1	tp 2	Mean	tp 1	tp 2	Mean	tp 1	tp 2	Mean
C_{SD}	67	78	89	79	72	77	67	67	100	77	70	74
Q_{mean}	78	67	67	51	56	65	67	67	67	47	44	58
Q_{SD}	78	56	56	51	47	56	67	67	78	42	40	51
CPP	67	78	89	77	72	79	67	56	89	72	70	74

Notes: FM, fidgety movements; CP, cerebral palsy; tp 1, test point 1; tp 2, test point 2; mean, mean of the two recordings; C_{SD}, centroid of motion standard deviation; Q_{mean}, quantity of motion mean; Q_{SD}, quantity of motion standard deviation; CPP, cerebral palsy predictor; p, probability of absent FMs and CP.

role of postterm age and number of assessments per infant on a quantitative video-based analysis for the detection of FMs and prediction of CP in young infants.

One assessment is considered sufficient for clinical GMA if FM can be observed (Einspieler et al, 2004). This suggests that a child demonstrating FMs at any time has an intact nervous system not compatible with later CP development. However, when using a single outcome from the quantitative movement analysis based on one video recording there is a risk of catching an extreme value of that individual's movements. Infants have large primary movement variability during the FM period (Hadders-Algra, 2010), and by averaging several measurements of the same individual, potentially extreme values are reduced into a more representative or "true" value for that individual. It is not known whether the measured movement variables may change with increasing age of the infant within the FM period. Bruggink et al (2009b) split their results during the FMs' period into the early FMs' period (6–10 weeks postterm), the mid-FMs' period (11–16 weeks postterm) and late or post-FMs' period (17–24 weeks postterm). Further, the quality of FMs has shown to remain highly consistent within one individual during a single recording (Mutlu, Einspieler, Marschik, and Livanelioglu, 2008). The present study demonstrates similar sensitivities and specificities of CP and FMs for early and late recordings during the mid-FM's period. A majority of the first recordings were done at postterm age 13–14 weeks, whereas the majority of the second recordings were done at 16–17 weeks. Since this study was not designed to detect age-dependent changes in movement variables, there was a small overlap between the first and second recordings in four infants. It cannot be concluded whether the results would have been different if first and second recordings were taken further apart (e.g., at the early or late FMs' period).

In a clinical setting with the follow-up of high-risk infants, the main goal will be to identify correctly those infants who will develop CP in order to initiate early intervention programs and include the infant in a close follow-up program. A cut-off for probability for disease which results in few false negatives will, therefore, be of high priority. Cut-off points presented in this study were chosen to balance sensitivities and specificities at acceptable levels for all data sets and image variables. Choosing a higher or lower cut-off point would consequently lead to more infants being classified as healthy or sick. The significance of improving sensitivity vs. specificity cannot be determined solely based on the results from a study like this, but has to take into consideration relevant clinical aspects.

The study population consisted of a convenience sample recruited from both the well-baby-ward and the NICU, and there was a high prevalence of absent FMs and CP (17% for both) in the study group. The total number of included infants and video recordings are small, and the sensitivities and specificities should be interpreted with caution. Despite this, the high area under curve indicates a good balance between sensitivity and specificity with good accuracy and is the most important measure of strength of the model. More and larger studies are needed in well-defined high-risk populations for further verification.

In accordance with previous studies (Adde et al, 2009, 2010) the C_{SD} was the strongest predictor of both absent FMs and CP at 2 years. Spontaneous movements in young infants involve the whole body, and they generate a subjective impression of complexity and variability (Adde et al, 2009; Einspieler and Prechtl, 2005; Einspieler et al, 2004; Prechtl, 1990). For the observation and assessment of GMs, complexity is interpreted as frequent changes in movement direction of all body parts, and variability as continuously new movement patterns produced by the infant. A recent kinematic description by Karch et al (2010) models complexity as the multivariate and simultaneous interactions in the kinematic chains of upper and lower limb movements. We believe that the variation of the centroid of motion (C_{SD}), as calculated from a video recording, reflects the complexity and variability perceived as relevant to the identification of FM by GMA, as well as the kinematical-based interpretation of complexity and variation by Karch et al (2010). Infants with a high C_{SD} value will have a more monotonous movement pattern where one part of the body moves without being followed by similar movements in the rest of the body. Frequent changes in movement direction of all body parts will give a stable centroid of motion and hence a low standard deviation value (C_{SD}).

The infant with present FMs and CP and the one with absent FMs and non-CP exhibited many and few concurrent GMs, respectively, when visual re-examination of the video recordings was performed. Although it is argued that FMs classification by GMA is not influenced by such concurrent movements (Einspieler et al, 2004), the previous results obtained by the computer-based method suggest that infants who later develop CP have lower values of Q_{mean} than those who do not develop CP (Adde et al, 2010). The low number of infants with FMs classifications not matching later CP outcome makes it difficult to interpret possible relations between concurrent GMs and the data-based variable Q_{mean} in this study. The combined variable CPP is demonstrated to have almost the same accuracy as C_{SD} in the present study. However, the small number of infants with absent FMs in this study makes it difficult to be certain which variable, the combined variable CPP or the C_{SD}, is the best. Limitations other than sample size might be why milder forms of CP may present later in childhood and that 3D movement cannot be fully captured with a single 2D camera. Results therefore need validation. Further research will hopefully reveal if there are other variables, or other combinations of variables, which can increase the accuracy of the computer-based method in detecting FMs and predict later CP.

CONCLUSION

Using two video recordings, rather than only one, improves the computer vision-based identification of FMs and prediction of CP by about 10%. The quantitative variable related to the variability of the centre of infant movement (C_{SD}) demonstrated the highest accuracy with respect to area under curve and sensitivity and specificity values. Postterm age at assessment during the FM period did not influence the accuracy of the method when only one recording was used for the analysis. Dependent on the outcome of future comparative tests; two recordings during the FM period may be suggested for clinical use. Results must be verified in larger studies.

Acknowledgments

This work was supported by the Liaison Committee between the Central Norway Regional Health Authority (RHA) and the Norwegian University of Science and Technology (NTNU), and the Department of Clinical Services, and Department of Pediatrics', Trondheim University Hospital, Trondheim, Norway.

***Declaration of interest*:** All authors disclose any actual or potential conflict of interest including any financial, personal, or other relationships with other people or organizations within that could inappropriately influence (bias) our work.

REFERENCES

Adde L, Rygg M, Lossius K, Oberg GK, Stoen R 2007 General movement assessment: Predicting cerebral palsy in clinical practise. Early Human Development 83: 13–18

Adde L, Helbostad JL, Jensenius AR, Taraldsen G, Stoen R 2009 Using computer-based video analysis in the study of fidgety movements. Early Human Development 85: 541–547

Adde L, Helbostad JL, Jensenius AR, Taraldsen G, Grunewaldt KH, Stoen R 2010 Early prediction of cerebral palsy by computer-based video analysis of general movements: A feasibility study. Developmental Medicine and Child Neurology 52: 773–778

Bruggink JL, Cioni G, Einspieler C, Maathuis CG, Pascale R, Bos AF 2009a Early motor repertoire is related to level of self-mobility in children with cerebral palsy at school age. Developmental Medicine and Child Neurology 51: 878–885

Bruggink JL, Einspieler C, Butcher PR, Stremmelaar EF, Prechtl HF, Bos AF 2009b Quantitative aspects of the early motor repertoire in preterm infants: Do they predict minor neurological dysfunction at school age? Early Human Development 85: 25–36

Burger M, Frieg A, Louw QA 2011 General movements as a predictive tool of the neurological outcome in very low and extremely low birth weight infants – A South African perspective. Early Human Development 87: 303–308

Cans C 2000 Surveillance of cerebral palsy in Europe: A collaboration of cerebral palsy surveys and registers. Surveillance of Cerebral Palsy in Europe (SCPE). Developmental Medicine and Child Neurology 42: 816–824

Einspieler C, Prechtl HF 2005 Prechtl's assessment of general movements: A diagnostic tool for the functional assessment of the young nervous system. Mental Retardation and Developmental Disabilities Research Reviews 11: 61–67

Einspieler C, Prechtl HF, Ferrari F, Cioni G, Bos AF 1997 The qualitative assessment of general movements in preterm, term and young infants – Review of the methodology. Early Human Development 50: 47–60

Einspieler C, Prechtl HF, Bos A, Ferrari F, Cioni G 2004 Prechtl̀s Method on the Qualitative Assessment of General Movements in Preterm, Term and Young Infants. New York, Mac Keith Press

Ferrari F, Todeschini A, Guidotti I, Martinez-Biarge M, Roversi MF, Berardi A, Ranzi A, Cowan FM, Rutherford MA 2011 General movements in full-term infants with perinatal asphyxia are related to basal ganglia and thalamic lesions. Journal of Pediatrics 158: 904–911

Hadders-Algra M 2010 Variation and variability: Key words in human motor development. Physical Therapy 90: 1823–1837

Karch D, Wochner K, Kim K, Philippi H, Hadders-Algra M, Pietz J, Dickhaus H 2010 Quantitative score for the evaluation of kinematic recordings in neuropediatric diagnostics. Detection of complex patterns in spontaneous limb movements. Methods of Information in Medicine 49: 526–530

Mutlu A, Einspieler C, Marschik PB, Livanelioglu A 2008 Intra-individual consistency in the quality of neonatal general movements.Neonatology 93: 213–216

Prechtl HF 1990 Qualitative changes of spontaneous movements in fetus and preterm infant are a marker of neurological dysfunction. Early Human Development 23: 151–158

Prechtl HF, Einspieler C, Cioni G, Bos AF, Ferrari F, Sontheimer D 1997 An early marker for neurological deficits after perinatal brain lesions. Lancet 349: 1361–1363

Spittle AJ, Doyle LW, Anderson PJ, Inder TE, Lee KJ, Boyd RN, Cheong JL 2010 Reduced cerebellar diameter in very preterm infants with abnormal general movements. Early Human Development 86: 1–5