Early Human Development 85 (2009) 541–547

Contents lists available at ScienceDirect

Early Human Development

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

Using computer-based video analysis in the study of fidgety movements

Lars Adde [a,*], Jorunn L. Helbostad [b,c], Alexander Refsum Jensenius [d], Gunnar Taraldsen [b], Ragnhild Støen [e,f]

[a] Department of Clinical Services, Physiotherapy section, St. Olav University Hospital, Trondheim, Norway
[b] Department of Neuroscience, Norwegian University of Science and Technology, Trondheim, Norway
[c] Geriatric Department, St. Olav University Hospital, Trondheim, Norway
[d] Department of Musicology, University of Oslo, Norway
[e] Department of Pediatrics, St. Olav University Hospital, Trondheim, Norway
[f] Department of Laboratory Medicine, Children and Woman's Health, Faculty of Medicine, Norwegian University of Science and Technology, Norway

ARTICLE INFO

Article history:
Received 26 February 2009
Received in revised form 29 April 2009
Accepted 1 May 2009

Keywords:
General movement assessment
Fidgety movements
Cerebral palsy
Infants
Neurological assessment
Video analysis
Computer vision

ABSTRACT

Objective: Absence of fidgety movements (FM) in high-risk infants is a strong marker for later cerebral palsy (CP). FMs can be classified by the General Movement Assessment (GMA), based on Gestalt perception of the infant's movement pattern. More objective movement analysis may be provided by computer-based technology. The aim of this study was to explore the feasibility of a computer-based video analysis of infants' spontaneous movements in classifying non-fidgety versus fidgety movements.
Method: GMA was performed from video material of the fidgety period in 82 term and preterm infants at low and high risks of developing CP. The same videos were analysed using the developed software called General Movement Toolbox (GMT) with visualisation of the infant's movements for qualitative analyses. Variables derived from the calculation of displacement of pixels from one video frame to the next were used for quantitative analyses.
Results: Visual representations from GMT showed easily recognisable patterns of FMs. Of the eight quantitative variables derived, the variability in displacement of a spatial centre of active pixels in the image had the highest sensitivity (81.5) and specificity (70.0) in classifying FMs. By setting triage thresholds at 90% sensitivity and specificity for FM, the need for further referral was reduced by 70%.
Conclusion: Video recordings can be used for qualitative and quantitative analyses of FMs provided by GMT. GMT is easy to implement in clinical practice, and may provide assistance in detecting infants without FMs.

1. Introduction

Preterm infants are at increased risk for adverse neurodevelopmental outcomes [1]. Up to 18% of surviving infants who are born extremely preterm develop cerebral palsy (CP) [2], and the total rate of neurological impairments is up to 45% [3–5]. Neuroimaging and clinical neurological examination during the neonatal period are used to assess the risk of later disabilities. Follow-up programs after discharge are implemented in most tertiary care centres caring for these infants in order to provide specific intervention programs and accurate information to parents about their infant's capabilities and prognosis.

A new approach to functionally assess the young nervous system has been presented by Prechtl [6–8]. Assessment of general movements (GMs), a part of the spontaneous movement repertoire, is a reliable and sensitive tool for the assessment of infant motor development [9,10]. In particular, the absence of the so-called fidgety movements (FMs) in infants at 9–20 weeks post-term age has been shown to be a marker for later disability and cerebral palsy in particular [7,11–13].

FMs are small movements of moderate speed with variable acceleration of neck, trunk, and limbs in all directions [7,14]. The quality of GMs is observed from video recordings and evaluated by trained observers, and the assessment of general movements is based on a global visual Gestalt perception described by Konrad Lorenz [15]. Lorenz described the mechanism of Gestalt perception as analogous to "subconscious conclusions", or as three classical steps of inductive natural science; accumulation of observations, systematic ordering of these observations and abstraction of a governing principle. Lorenz highlighted the danger of attending details and loosing the Gestalt perception that is sought [15]. It is, therefore, crucial that the general movement assessment (GMA) observer masters the principle of not focusing on any details in the infant movements during the assessment.

Due to the experience that is needed and the qualitative nature of GMA, the implementation, generalizability and overall utility of the method have been questioned [11,16,17]. There are indications that

Abbreviations: GM, general movement; FM, fidgety movement; GMA, general movement assessment; GMT, general movement toolbox.

* Corresponding author. Department of Clinical Services, Physiotherapy Section, St. Olav University Hospital, N-7006 Trondheim, Norway. Tel.: +47 91897615; fax: +47 72574560.
E-mail address: lars.adde@ntnu.no (L. Adde).

0378-3782/$ – see front matter © 2009 Elsevier Ireland Ltd. All rights reserved.
doi:10.1016/j.earlhumdev.2009.05.003

GMA is limited in use in ordinary clinical practice [18]. The Gestalt perception technique requires experience, and clinicians working alone will be at risk of drifting away from the GMA standards over time. Verification of a GMA result needs a second opinion from another experienced GMA observer. Computer-based analysis of GMs, and the incorporation of its results in clinical follow-up programs may offer a supplement to existing clinical methods.

New motion capture technologies have made it possible to perform quantitative analyses of movement and, thereby, discrimination of normal versus pathological movement based on objective criteria. However, such methods are often restricted to laboratories because of the need for comprehensive instrumentation and advanced analyses [19–22]. To be the first choice in clinical practice, computer-based analysis should be quick to set up, easy to use, and noninvasive for the subjects being studied. Recently, by the use of 2D video recordings, Jensenius et al. [23] developed the Musical Gesture Toolbox (MGT), a software collection for performing video analysis of music-related movements in musicians and dancers. In addition to extracting quantitative measures from the movement in the video recording, the MGT also visualises the qualities of movement. One visualisation method is the *motiongram*, a 2D representation of movement over time [24]. For this study we have developed the General Movement Toolbox (GMT) as a software solution for studying general movements in young infants.

The aim of this study is to 1) describe the usability of *motiongrams* in the study of FMs, and 2) by using the GMT and quantitative parameters, to investigate the ability to detect non-fidgety versus FMs.

2. Subjects and methods

2.1. Subjects

The study group was recruited from St. Olav University Hospital, Trondheim, Norway. Most infants had participated in a previous study on GMA [11]. A convenience sample of preterm and term infants at low or high risk of neurological impairment was included during the period from 2002 to 2004. Infants born after 28 weeks of gestation without any pre- or postnatal complications were considered to be at low risk for neurodevelopmental disorders. Infants were considered to be at high risk of neurodevelopmental disorders if they had a gestational age lower than 28 weeks and/or a birth weight below 1000 g at birth, or had specific risk factors as described elsewhere [11]. All infants had at least one video recording of GMs available during the fidgety movements' period. Written consent was obtained from all parents, and The Regional Committee for Medical Research Ethics and Norwegian Social Science Data Services approved the study.

2.2. Video recordings

The number of recordings performed on each infant varied from 1–5, and recordings were performed between 10 and 18 weeks post-term age. As infant movements were also used for 3D electromagnetic sensor measurements, all infants had motion tracking sensors attached to each extremity, on the sternum and on the forehead. Recordings were done with the infant placed in supine position on a standard mattress during active wakefulness, wearing a diaper and a body. Movements were recorded with a stationary digital video camera (Sony DCR-PC100E) placed above the infant. The GMA observer (LA) edited each video recording according to the procedure described by Einspieler [14]. The edited recordings of 3–15 min were the basis for the GMA. In order to optimize the material for analysis using the GMT, all videos were later cut down to 0.5–5 min sequences. In this last editing process, all movements due to sensor wire movements or other disrupting movements in the video image were omitted.

2.3. Quality of general movements

The GMs were classified following the Prechtl's method of GMA [14], and FMs were defined according to the definition of Prechtl [7]. The FMs were classified as normal when they were present (F+ if intermittent, or F++ if continuous), or as abnormal if they were absent (F−) or abnormal in nature (Fa), i.e. if they looked like normal FMs but their amplitude, speed and jerkiness were moderately or greatly exaggerated. Classification of FMs by GMA was further used as the gold standard for the evaluation of the General Movement Toolbox analysis.

2.4. The Musical Gesture Toolbox (MGT)

The Musical Gesture Toolbox has been developed by Jensenius et al. in 2004 and was made available as open source software in 2005 [23]. It was developed for studying various types of music-related movements (e.g. sound-producing, ancillary, and communicative), and contains tools for playing video, making image adjustments, cropping, and carrying out different types of qualitative and quantitative analyses both in real time and non-real time. For quantitative analyses, the MGT outputs numerical data, whereas various visual representations are used for observation and qualitative analyses. For the purpose of studying GM qualities, MGT was customized into the General Movement Toolbox (GMT) by making some changes in the graphical user interface and removing some software modules specially designed for the study of music-related movements.

2.5. The General Movement Toolbox (GMT)

The General Movement Toolbox includes the following parts and functions: 1) playback of pre-recorded video files, 2) pre-processing the video by cropping the image to the desired observable area, 3) calculation of the motion image, 4) filtering the motion image, 5) creation of motiongrams for visual inspection and 6) calculation and export of quantitative features from the motion image. The graphical user interface (GUI) of GMT is shown in Fig. 1. In a typical workflow, the user opens a pre-recorded video file, plays the video using the tools in the upper left corner (Fig. 1), crops the image to the desired area by clicking in the preview window, and selects the appropriate pre-processing settings.

All video recordings in the present study were cropped so that only a window containing the mattress with the infant was left for further analysis (Fig. 1). After cropping, the motion image was created by identifying the change for each pixel between two frames (Fig. 1). In a motion image each pixel represents a point value of 0 and 1, 0 being black and representing no movement, and 1 being white and representing movement. Depending on the quality of the original video, the motion image must be filtered before carrying out further analyses. Two different filtering techniques were tested on 20 video recordings containing both normal and abnormal qualities of GMs: a) simple low pass filter where all pixels below a fixed threshold were removed, and b) the same low pass filter as in a) applied after a spatial noise reduction where single or clusters of pixels falling below a certain size were removed. Method b) was chosen after visual inspection of the prepared videos by a GM expert observer (LA), and the threshold level set at 0.05 for all recordings (Fig. 2). The threshold was chosen to give the optimal combination of maximum visible movement and low noise details occurring from patterns in clothing and the wires attached to the extremities. The final motion image provided the data for further qualitative and quantitative analyses.

2.6. Motiongram

A motiongram can be seen as a representation of the motion image, where each motion image frame is averaged to a one pixel wide

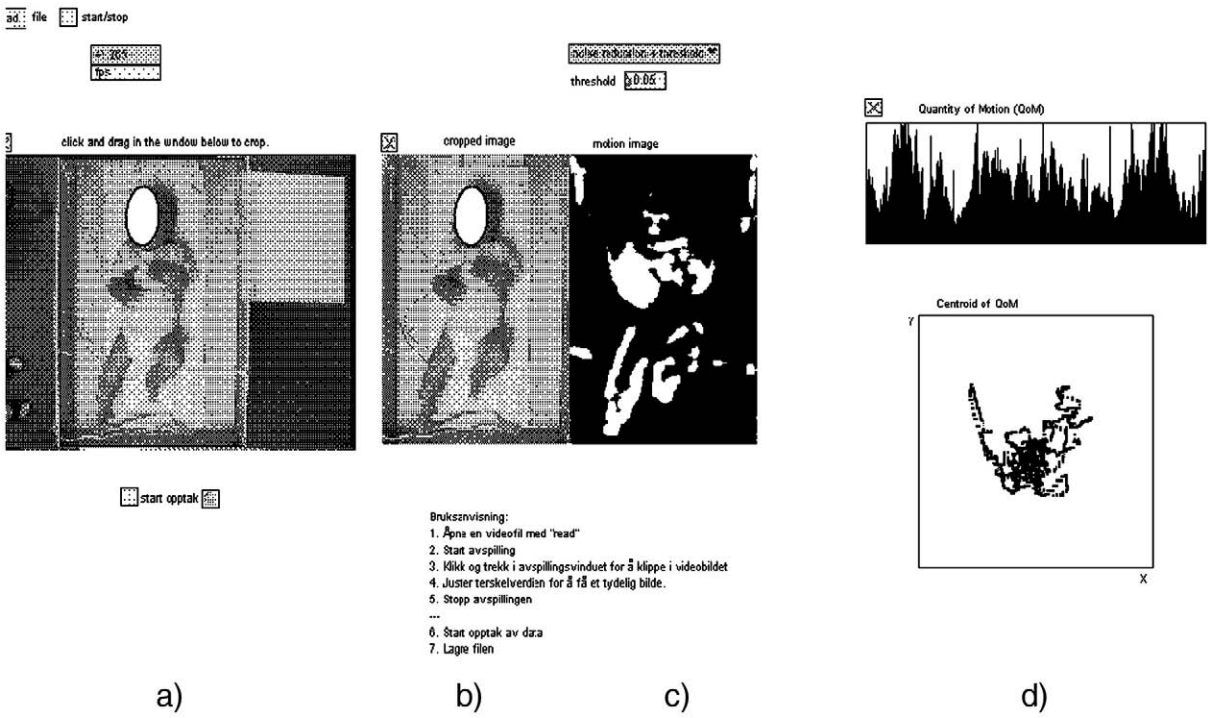

Fig. 1. The GMT graphical user interface: a) input video, b) cropped video and c) motion image. d) The upper section; display of quantity of motion, the lower section; display of the centroid of motion. The tuning and threshold button is above the motion image in the interface and pre-recorded video file is browsed by clicking in the upper left corner of the interface.

or tall matrix being plotted over time. This results in either a horizontal or vertical motiongram display. Fig. 3 shows horizontal motiongrams of one infant with present and one with absent FMs. Movements of upper and lower extremities are seen at the top and the bottom of the image, respectively, and the limited movements of the trunk are seen in the middle part of the motiongram. Although a reduction of the original video, the motiongram gives an indication of how much the infant is moving over time, as well as where in the body the movement is happening.

2.7. Quantitative measures

Quantity of motion is calculated as the sum of all pixels that change between frames in the motion image divided by the total number of pixels in the image. This gives values ranging between 0 and 1, where 1 means that all pixels changed between the two frames, and 0 means that no pixels changed between frames. Quantity of motion can therefore be used as an estimate of movement from a video sequence as shown in Fig. 1. The mean values (Q_{mean}), maximum values (Q_{max})

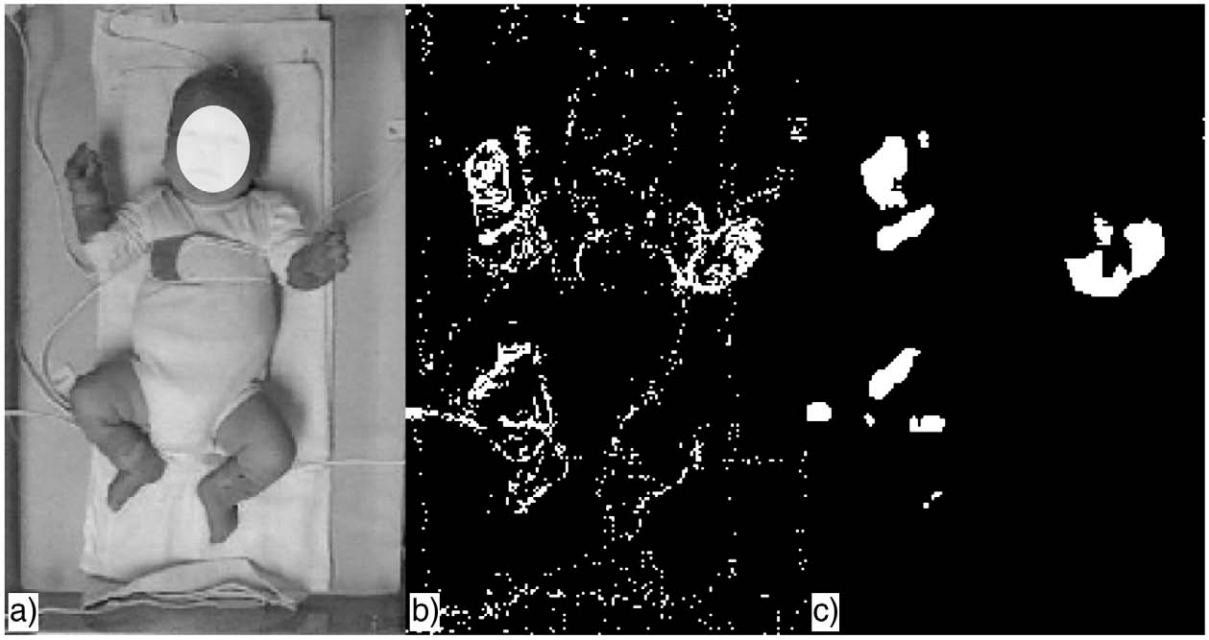

Fig. 2. Illustration of the difference between adding the noise reduction algorithm after low pass filtering the image. From left: a) cropped input image, b) motion image with low pass filter threshold 0.05, and c) motion image with added noise reduction algorithm before low pass filter with threshold 0.05.

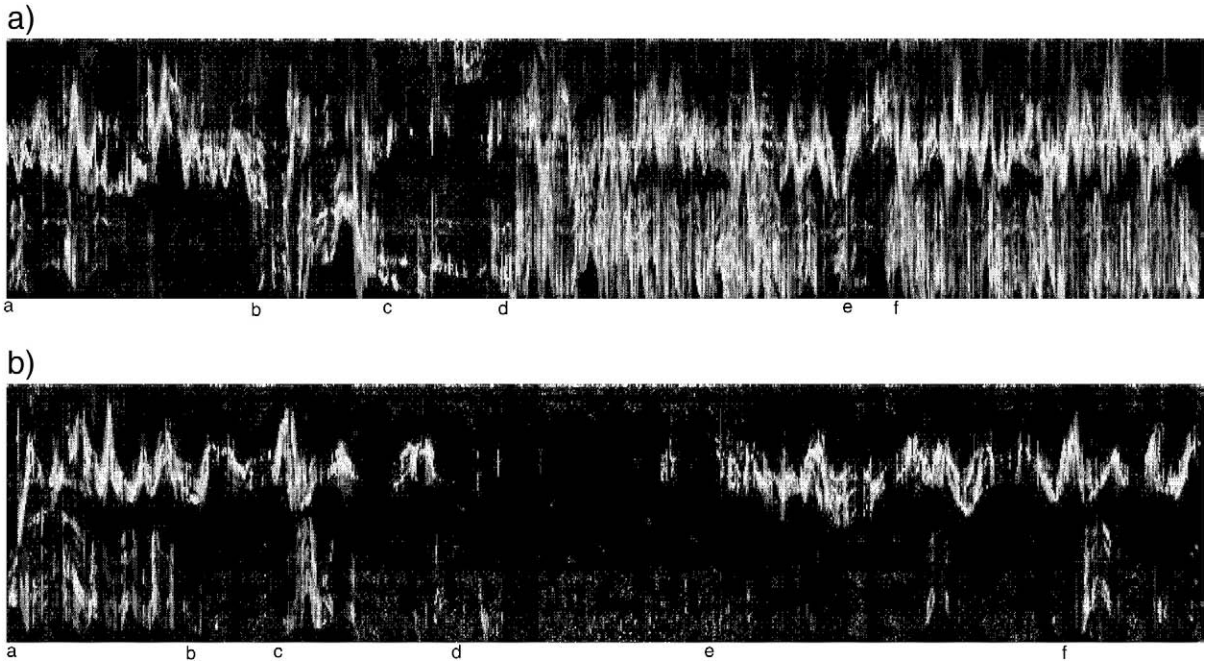

Fig. 3. Examples of displays with motiongrams; a) sequence containing movements for an infant with FMs and b) a movement sequence for an infant with absent FMs. Time running along the *x* axis, and vertical movements on the *y* axis.

and standard deviation (Q_{SD}) were calculated for the quantity of motion for each recording and served as outcome variables. The *centroid of motion* is the spatial centre of the positive pixels in the motion image, and may be seen as a correlate to the centre point of the movements of the infant. Fig. 1 displays how the centroid of motion is changing position during a video sequence. The mean values of centroid of motion in the *x*- and *y*-directions were calculated (Cx_{mean}, Cy_{mean}). The variability of the centroid of motion as a function of time was quantified as the standard deviation given by time averaging. The resulting scalar quantity is the standard deviation of the centroid (C_{SD}). The variability of velocity and acceleration of the centroid of motion were given as time derivates, and the standard deviation of these giving two further quantities; the standard deviation of the velocity (V_{SD}) and the standard deviation of the acceleration (A_{SD}).

2.8. Statistics

Quantitative data were exported as Ascii files using the non-real time mode of GMT. Data were analysed using Matlab version R2008a and SPSS version 15.0. Data were tested for normality distribution using a Kolmogorov–Smirnov test in the group with present FMs, but not in the group with absent FMs due to its small sample size. The estimated group means with standard error for infants with absent and present FMs were calculated. Between-group differences were tested by using independent sample *t*-tests. Sensitivity and specificity analyses were performed for each outcome variable and presented as receiver operating characteristic (ROC) curves. Area under the curve was also calculated as a measure of strength of the model. Logistic-regression models on fidgety versus non-fidgety as dependent variable were performed to investigate the strength of the association between the dependent and each of the independent variables. The association between age at the time of assessment and length of the final video recording on the motion image variables was explored using a Pearson correlation test. By the use of a logistic-regression enter model we assessed whether a combination of motion image variables would give higher sensitivity and specificity than only single variables.

A triage test [25] based on data from the General Movement Toolbox was used as an adjunct to clinical GMA for diagnosis of FMs. We defined a GMT sensitivity (the ability to identify absence of FMs) of 90% and specificity (the ability to identify the presence of FMs) of 90 and 80%. Values classified above the upper threshold were likely to have absent FMs and recordings classified below the lower threshold were likely to have present FMs. Recordings falling between the two thresholds would be recommended for referral for clinical GMA.

3. Results

Eighty-two infants at high ($n=32$) and low ($n=50$) risks for later neurological impairments were included. The study group consisted of 37 boys and 45 girls. Forty-eight infants (58.5%) were born preterm. In the preterm group, the median gestational age was 29.5 weeks (range 23–36) and median birth weight was 1910 g (range 470–3350). A total of 137 video recordings were obtained from the 82 participating infants in the period 10–18 weeks post-term age with a median recording age of 13 weeks. The median length of the video recordings used for quantitative analysis was 3.3 min (range 0.5–5.1). Out of 137 recordings, 27 were classified with absent FMs and 110 with observable FMs by GMA. None of the recordings was classified with FMs that was abnormal in nature.

Two motiongrams from the real time mode of the GMT are shown in Fig. 3a and b, representing one infant with and one infant without FMs,

Table 1
Between-group differences between present and absent FMs in variables derived from the GMT.

	Present FMs (110)	Absent FMs (27)	Between-group differences	
	Mean (SE)	Mean (SE)	*p*-value	95% CI
Q_{mean} (%)	2.95 (0.15)	1.79 (0.17)	<.001	(0.71, 1.62)
Q_{max} (%)	32.70 (1.87)	29.04 (2.70)	.269	(−2.92, 10.24)
Q_{SD} (%)	3.20 (0.13)	2.41 (0.17)	<.001	(0.37, 1.22)
Cx_{mean}	4.65 (0.06)	4.49 (0.15)	.328	(−0.17, 0.50)
Cy_{mean}	4.31 (0.06)	4.01 (0.17)	.107	(−0.69, 6.73)
C_{SD}	2.17 (0.05)	2.82 (0.10)	<.001	(−0.09, −0.04)
V_{SD}	6.35 (0.18)	8.29 (0.42)	<.001	(−2.86, −1.01)
A_{SD}	1.03 (0.03)	1.35 (0.07)	<.001	(−0.48, −0.17)

Q_{mean} = quantity of motion mean; Q_{max} = quantity of motion maximum; Q_{SD} = quantity of motion standard deviation; Cx_{mean} = centroid of motion in *x*-direction mean; Cy_{mean} = centroid of motion in *y*-direction mean; C_{SD} = centroid of motion standard deviation; V_{SD} = velocity standard deviation; A_{SD} = acceleration standard deviation.

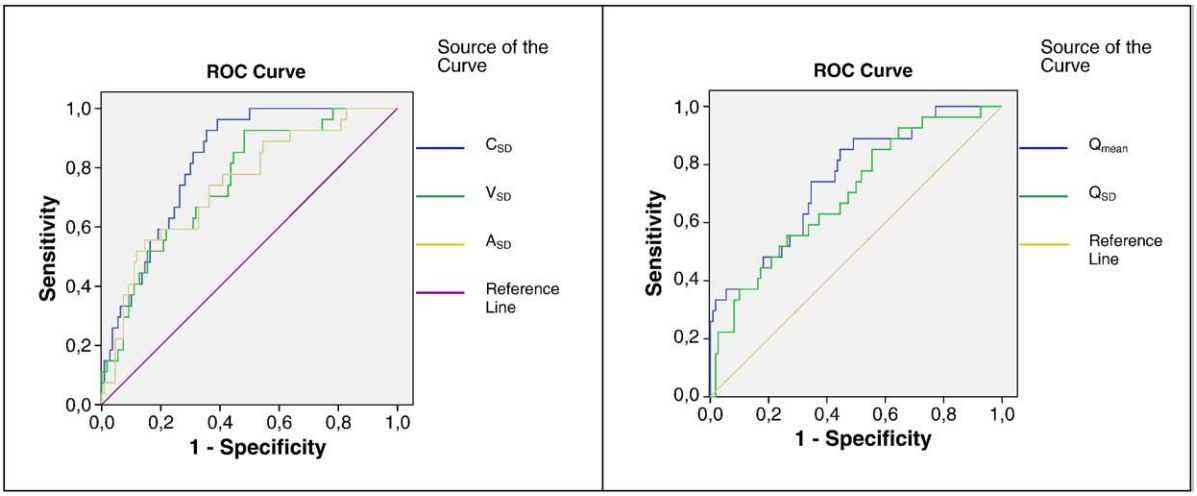

Fig. 4. Receiver operating characteristic curves for the FM diagnostic variables C_{SD}, V_{SD}, A_{SD}, and Q_{mean}, Q_{SD}.

respectively. By observing the original video and the motiongram in parallel, the sequence displayed in the motiongram in Fig. 3a was described as follows by a GM observer (LA): a) ongoing FMs with small amplitude in both arms, little movements in legs, b) leg lifts with flexed knees and some minor arm movements, c) almost no spontaneous movements present, d) ongoing FMs involving the whole body, e) a short pause in the leg movements, and f) continuation of FMs. The video sequence in Fig. 3b without FMs was described as follows: a) spontaneous movements with some leg kicking and synchronized swiping movements in both arms, b) stiff legs that are not moving and minor cramped-synchronized movements in arms, c) some spontaneous, but monotonous movements in all extremities, d) infant is not moving and lies in a stiff, cramped position, e) cramped-synchronized movements in arms and no leg movements, and f) one single synchronous leg kick in addition to the cramped-synchronized arm movements.

Despite the impression of similar motiongrams at the start of the sequences in Fig. 3a and b, specific differences can easily be identified. In sequence 3a, which was a representative motiongram of infants with FMs, there were fewer periods with no movement at all, and during periods of movement, the motiongram density was higher and more evenly distributed. This indicates a motiongram pattern corresponding to clinical observations of a fluent movement pattern with simultaneous movements of neck, trunk and limbs in infants with FMs.

By observing the displays of quantity of motion (Fig. 1) in two infants with present and absent FMs, respectively, the infant with FMs had more overall movements with motions distributed in a regular or cyclic manner. In the display of centroid of motion (Fig. 1) from the infant with FMs, the space covered by the centroid movements was smaller and more circular than the infant without FMs. Furthermore, the infant with absent FMs had a more asymmetrical shape of the total distribution of movements and a larger total area covered by movements.

Table 2
Specificity and area under the curve for variables derived from GMT when sensitivity was set to 81.5%.

	Sensitivity	Specificity	AuC	CI95%	Threshold
Q_{mean}	81.5	44.4	0.75	(0.65, 0.85)	1.46
Q_{SD}	81.5	44.4	0.70	(0.59, 0.81)	2.14
V_{SD}	81.5	56.0	0.75	(0.66, 0.85)	6.37
A_{SD}	81.5	46.4	0.74	(0.64, 0.85)	0.97
C_{SD}	81.5	70.0	0.83	(0.75, 0.90)	2.32

AuC = area under curve; Q_{mean} = quantity of motion mean; Q_{SD} = quantity of motion standard deviation; V_{SD} = velocity of motion standard deviation; A_{SD} = acceleration of motion standard deviation; C_{SD} = centroid of motion standard deviation.

Three quantity of motion and five centroid of motion variables with area under curve values above 0.70 in ROC plots were chosen for further analyses (Table 1). Recordings with absent FMs had significantly lower mean quantity of motion but higher variability of the centroid of motion, acceleration and velocity than infants with present FMs. ROC curves for variables that were significantly different between groups are plotted in Fig. 4. The area under the curve and comparable sensitivity and specificity values for all the variables are shown in Table 2. Logistic regression on each of the movement variables demonstrated that variability of centroid of motion had the strongest association with the absence of FMs. Neither length of video recording or age at time of assessment correlated with variability of centroid of motion ($r = 0.01$ and $r = 0.04$, respectively). Using a combination of movement variables as independent variables did not change the variability of the model ($R^2 = 0.30$), and thus only variability of the centroid of motion was used in the further analyses.

For the variability of centroid of motion, a sensitivity of 81.5% corresponded to a specificity of 70.0% for the detection of absent FMs. A triage method, where results between the set thresholds indicate need for referral to clinical GMA, was applied in order to improve the accuracy. Upper and lower triage thresholds of 90% sensitivity and specificity were chosen, resulting in 20 recordings (15%) falling above upper threshold and 73 (53%) falling below lower threshold. Hence, 44 recordings were regarded as being in need of referral. Lowering the specificity to 80% resulted in 26 recordings which needed referral to further GMA assessment. The numbers of video recordings falling into each triage group, and the number of recordings in need for referral to clinical GMA with two different pair of thresholds, are shown in Table 3.

Table 3
Triage threshold analysis of variability of the centroid of motion (C_{SD}).

Thresholds C_{SD}	Spec: 90% Sens: 90%	Spec: 80% Sens: 90%
–Upper	2.93	2.67
–Lower	2.24	2.24
	Number of video recordings	
Above upper threshold: follow-up/treat		
Absent FMs	9	16
Present FMs	11	22
Between thresholds: refer		
Absent FMs	16	9
Present FMs	28	17
Below lower threshold: reassure		
Absent FMs	2	2
Present FMs	71	71
Referral rate	32.1%	19.0%

4. Discussion

The custom-built GMT proved to be a feasible method to generate qualitative and quantitative data based on video recordings of general movements in young infants. Visual representations of the quantity of motion, centroid of motion and motiongrams in particular, can be used for visualisation and qualitative analysis of FMs. Furthermore, quantitative analysis of the variability of centroid of movement proved to be an objective measure to classify the absence or presence of FMs. By employing the GMT in a triage role, the need for further referral could be reduced to 30%. To the best of our knowledge, this is the first study to demonstrate a computer-based method for classification of infants' FMs.

A motiongram is based on a simple reduction of the original motion image, and there is no specific analysis taking place in this process [24]. The presence of observable FMs in the infant's movement repertoire corresponded to recognisable patterns in the motiongram. A continuous motiongram pattern with high density and smooth distribution was present in the sequences containing FMs, giving the impression of a harmonic and periodical movement pattern. The visualisation of quantity of motion showed similar patterns appearing in a regular and smoothly distributed way. The centroid of motion in infants with FMs appeared in a circular manner with small amplitude, continuously making small changes in different directions. Larger amplitudes and less variation of the centroid of motion corresponded to a more monotonous and stereotype movement pattern in infants without FMs. Hence, it can be argued that all GMT qualitative representations reflect some of the significant qualities observed by a GMA observer when classifying present FMs. Whether visual observation of motiongrams may provide assistance to the clinical GMA, must be a subject for further research.

Quantitative features reflecting overall movements were analysed. The mean values of quantity of motion discriminated between infants with and without FMs, demonstrating that the amount of movement is significant. In 3- to 6-month-old infants the FMs are described to superimpose concurrent movements [14]. Whether higher mean quantity of motion values expresses FMs only or also concurrent movements cannot be concluded based on the present study. Larger variability of centroid of motion values in infants with absent FMs, may suggest a less stable movement pattern where the centroid of motion changes more over time. The variation in velocity and acceleration of the centroid of motion also discriminated between groups and may possibly be related to movement fluency. However, these outcomes did not improve the sensitivity of the method beyond the variability of the centroid of motion.

The length of the edited video recording used for analysis did not influence the GMT classification results. A minimum of 30 s per edited recording length was long enough to capture and classify features specific for FMs, suggesting a robust computer-based method. Neither did the age at the time of recording influence the results. This confirms that the age range chosen in the present study (10–18 weeks) was well within the age range defined as fidgety movements' age by Prechtl et al. [14].

Recently a relationship between GMs and cerebral white matter abnormalities on MRI has been demonstrated. In very preterm infants (<30 weeks gestation), abnormal FMs at 3 months correlated with white matter abnormality on MRI, suggesting that abnormal FMs reflect white matter injury [1]. Despite MRI obtained without sedation and anesthesia, the MRI method is expensive and not easily accessible. MRI qualitative scoring of white matter abnormalities requires top competence and will be limited to certain centres. The GMT is non-intrusive and based on an already established clinical method of evaluating infants' general movements. It is easy to use and requires little training. One day was sufficient to manage the software application, and results of the analysis were available after 10–15 min. This study represents the first evaluation of a new method, and it will need further development for general clinical use. The GMT may provide assistance for more focused follow-up programs for those with very high probability of developing CP. It may also be a valuable tool for research on early intervention programs for high-risk infants.

The population in our study is a convenience sample of infants with a high prevalence of absent FMs (19.7%). Referral rate using the triage model will differ depending on the prevalence of disease in the population studied. The results must, therefore, be interpreted with caution, and studies on well-defined, high-risk populations must be carried out. Long term neurological outcome was not yet collected at the time of the present study. A previous study by our group, however, has demonstrated a very high correlation between absent FMs and CP at 2 years follow-up [11]. It is therefore a reason to believe that absent FMs in this study predict later CP.

5. Conclusion

The present study demonstrates a novel, non-intrusive and easily applicable computer-based method to identify the presence of FMs in young infants. A motiongram based on a video recording displayed similar qualitative features as the clinical GMA. Quantitative features related to the quantity of motion and the variability of the centre of movement, were significantly associated with the presence of FMs. More studies are needed on well-defined high-risk populations. The accuracy of CP prediction using the GMT must be assessed in future studies with long-term neurological outcome.

Acknowledgements

This work was supported by the Department of Clinical Services and Department of Pediatrics, Trondheim University Hospital, in Trondheim. We thank physiotherapist Toril Fjørtoft for invaluable discussions about GMA, Øyvind Stavdahl for technical assistance and all health professionals contributing to data acquisition in our study.

References

[1] Spittle AJ, Brown NC, Doyle LW, Boyd RN, Hunt RW, Bear M, et al. Quality of general movements is related to white matter pathology in very preterm infants. Pediatrics 2008;121:1184–9.
[2] Larroque B, Ancel PY, Marret S, Marchand L, Andrè M, Arnaud C, et al. Neurodevelopmental disabilities and special care of 5-year-old children born before 33 weeks of gestation (the EPIPAGE study): a longitudinal cohort study. Lancet 2008;371:813–20.
[3] Marlow N, et al, for the EPICure Study Group. Neurologic and developmental disability at six years of age after extremely preterm birth. N Engl J Med 2005;352:9–19.
[4] Bracewell M, Marlow N. Patterns of motor disability in very preterm children. Ment Retard Dev Disabil Res Rev 2002;8:241–8.
[5] Schmidhauser J, Caflisch J, Rousson V, Bucher HU, Largo RH, Latal B. Impaired motor performance and movement quality in very-low-birthweight children at 6 years of age. Dev Med Child Neurol 2006;48:718–22.
[6] Einspieler C, Prechtl HFR. Prechtl's assessment of general movements: a diagnostic tool for the functional assessment of the young nervous system. Ment Retard Dev Disabil Res Rev 2005;11:61–7.
[7] Prechtl HFR, Einspieler C, Cioni G, Bos AF, Ferrari F, Sontheimer D. An early marker for neurological deficits after perinatal brain lesions. Lancet 1997;349:1361–3.
[8] Einspieler C, Prechtl HFR, Ferrari F, Cioni G, Bos AF. The qualitative assessment of general movements in preterm, term and young infants — review of the methodology. Early Hum Dev 1997;50:47–60.
[9] Valentin T, Uhl K, Einspieler C. The effectiveness of training in Prechtl's method on the qualitative assessment of general movements. Early Hum Dev 2005;81:623–7.
[10] Fjørtoft T, Einspieler C, Adde L, Strand LI. Inter-observer reliability of the "Assessment of motor repertoire-3 to5 months" based on video recordings of infants. Early Hum Dev 2009;85:297–302.
[11] Adde L, Rygg M, Lossius K, Øberg GK, Støen R. General movement assessment: predicting cerebral palsy in clinical practise. Early Hum Dev 2007;83:13–8.
[12] Seme-Ciglenecki P. Predictive value of assessment of general movements for neurological development of high-risk preterm infants: comparative study. Croat Med J 2003;44:721–7.
[13] Hadders-Algra M. General movements: a window for early identification of children at high risk for developmental disorders. J Pediatr 2004;145:12–8.
[14] Einspieler C, Prechtl HFR, Bos AF, Ferrari F, Cioni G. Prechtl's method on the qualitative assessment of general movements in preterm, term and young infants. London: Mac Keith Press; 2004 (Clinics in Developmental Medicine No. 167).

[15] Lorenz K. Gestalt perception as a source of scientific knowledge. English translation from a German paper in 1959. In: Lorenz K, editor. Studies in animal and human behaviour, vol II. London: Methuen; 1971. p. 281–322.
[16] Palmer FB. Editorial: first, observe the patient. Arch Pediatr Adolesc 2002;156:422–3.
[17] Palmer FB. Strategies for the early diagnosis of cerebral palsy. J Pediatr 2004;145:8–11.
[18] Garcia JM, Gherpelli JLD, Leone CR. The role of spontaneous general movement assessment in the neurological outcome of cerebral lesions in preterm infants. J Pediatr 2004;4:296–304.
[19] van der Heide JC, Paolicelli PB, Boldrini A, Cioni G. Kinematic and qualitative analysis of lower-extremity movements in preterm infants with brain lesions. Phys Ther 1999;79:546–57.
[20] Robertson SS, Bacher LF, Huntington NL. Structure and irregularity in the spontaneous behaviour of young infants. Behav Neurosci 2001;115:758–63.
[21] Conover MS. Using accelerometers to quantify infant general movements as a tool for assessing motility to assist in making a diagnosis of cerebral palsy. Master of Science in Mechanical Engineering. Blackburg, Virginia: Faculty of the Virginia Polytechnic Institute and State University; 2003.
[22] Meinecke L, Breitbach-Faller N, Bartz C, Damen R, Rau G, Disselhorst-Klug C. Movement analysis in the early detection of newborns at risk for developing spasticity due to infantile cerebral palsy. Hum Mov Sci 2006;25:125–44.
[23] Jensenius AR, Godøy RI, Wanderley MM. Developing tools for studying musical gestures within the Max/MSP/Jitter environment. In Proceedings of the International Computer Music Conference, 4-10 September, 2005, Barcelona, Spain, pp. 282-285. San Francisco: ICMA.
[24] Jensenius AR. Using motiongrams in the study of musical gestures. In Proceedings of the 2006 International Computer Music Conference, 6-11 November, New Orleans, pp 499-502. San Francisco: ICMA.
[25] Thorpe JA, Steel SA. The Alara Metriscan phalangeal densitometer: evaluation and triage thresholds. Br J Radiol 2008;81:778–83.