Abstract

Background:

Previous evidence suggests that the variability of the spatial center of infant movements, calculated by computer-based video analysis software, can identify fidgety general movements (GMs) and predict cerebral palsy.

Aim:

To evaluate whether computer-based video analysis quantifies specific characteristics of normal fidgety movements as opposed to writhing general movements.

Methods:

A longitudinal study design was applied. 27 low-to moderate-risk preterm infants (20 boys, 7 girls; mean gestational age 32 [SD 2.7, range 27-36] weeks, mean birth weight 1790 grams [SD 430g, range 1185-2700g]) were videotaped at the ages of 3 to 5 weeks (period of writhing GMs) and 10 to 15 weeks (period of fidgety GMs) post term. GMs were classified according to Prechtl's general movement assessment method (GMA) and by computer-based video analysis. The variability of the centroid of motion (C_{SD}), derived from differences between subsequent video frames, was calculated by means of computer-based video analysis software; group mean differences between GM periods were reported.

Results:

The mean variability of the centroid of motion (C_{SD}) determined by computer-based video analysis was 7.5% lower during the period of fidgety GMs than during the period of writhing GMs (p=0.004).

Conclusion:

Our findings support that the variability of the centroid of motion reflects small and variable movements evenly distributed across the body, and hence shows that computer-based video analysis qualifies for assessment of direction and amplitude of FMs in young infants.

<u>Keywords</u>

General movement assessment

Fidgety movements

Computerized GM assessment

Cerebral palsy

Abbreviations

GMA   general movement assessment

GMs   general movements

FMs   fidgety movements

Q   quantity of motion

C   centroid of motion

C_{SD} variability of the centroid of motion

INTRODUCTION

Early identification of cerebral palsy (CP), the major motor disability caused by preterm birth (Serenius et al., 2013), is important for early intervention and specific follow-up, but also to give certainty to parents whose children are unlikely to develop CP (Novak, 2014). Prechtl's qualitative assessment of general movements (GMA) can be used as a tool for early identification of infants with neurodevelopmental disabilities, especially during the period of fidgety movements (FMs; 9-18 weeks post-term age) (Burger and Louw, 2009; Noble and Boyd, 2012; Yang et al., 2012; Prechtl et al., 1997; Einspieler et al., 2004). GMA is based on visual Gestalt perception, which requires well-trained and experienced observers; wherever these are not available, widespread clinical use of GMA is not feasible. One of many systematic reviews concluded that more detailed evidence of the predictive value of GMA was required to support its use in clinical routine (Darsaklis, Snider, Majnemer and Mazer, 2011).

A complementary thinking on GMA has evolved based on recent studies which assessed general movements (GMs) with computer-based methods (Karch et al., 2010; Karch et al., 2012; Kanemaru et al., 2013; Valle et al., 2015; Marcroft et al., 2015; Adde et al., 2013). For a comprehensive evaluation of the integrity of the developing nervous system, observation and computer-based analysis of GMs may complement each other (Einspieler and Marschik, 2013).

Most motion capture systems use on-body markers or sensors. They provide very precise and accurate data about the kinematics and kinetics of human motion, often in combination with force plates and physiological sensors. However, there are also a number of drawbacks to

such motion capture systems: they tend to be very expensive, must be installed in a controlled environment, require subjects to wear sensors (sometimes connected to cables), and they require calibration as well as experts for advanced analyses and interpretation of the recorded data (Marcroft et al., 2015). Such systems are especially difficult to use in high-risk infants, who may be sensitive to instrumentation that might influence their behavioral state and well-being, and consequently the quality of their GMs. Our group has carried out three studies on a novel computer-based video software system developed to detect FMs at a post-term age of 10 to 18 weeks, and for the prediction of CP (Adde et al., 2009; Adde et al., 2010; Adde et al., 2013). The software calculates differences in pixel values between subsequent video frames, and exports motion variables reflecting the amount of motion and distribution of the infant's movements in the video. This type of non-invasive computer-based video analysis requires a standard, commercially available video camera but no instrumentation on the infant, which makes it preferable to other computer-based methods.

GMs involve the whole body in a variable sequence of arm, neck and trunk movements (Prechtl, 1990). At term age and until about 6 to 9 weeks post-term age, they are called writhing movements and are characterized by an ellipsoid form. At 6 to 9 weeks post term, these writhing, ellipsoid GMs are replaced by FMs (Prechtl, 1997). FMs are small movements of moderate speed and variable acceleration of the neck, trunk and limbs in all directions; they are continual in the awake infant, except when fussing and crying; their absence is a particularly strong marker for later CP (Einspieler et al., 2004). Our previous studies (Adde et al., 2009; Adde et al., 2010) suggest that some aspects of the movement pattern relevant for the identification of FMs and later CP are reflected in the computer-based movement parameter "Variation of the centroid of motion", i.e. the variable displacement of the spatial

center of the infant's movements. Because the transformation from writhing to FMs involves their decrease in amplitude and change in character from ellipsoid to small and circular, it has been hypothesized for infants displaying normal GM patterns that the displacement of the spatial center should also decrease in this process.

The aim of the present study was to determine whether computer-based video analysis can quantify specific characteristics of normal FMs as opposed to writhing movements.

METHODS

Design

The present study is a longitudinal cohort study of preterm infants in China whose GMs were assessed for their quality at 3 to 5 weeks post term (period of writhing movements) and at 10 to 15 weeks post term (period of FMs) by means of observation and computer-based video analyses. The same video-clips were used for both assessment methods.

Subjects

Preterm infants with a low to moderate risk of adverse neurological outcome were recruited between September 2012 and August 2013 at the Children's Hospital of Fudan University in Shanghai, China. Inclusion criteria were: 1) preterm birth at 27-36 weeks gestational age (GA), and 2) existing videos of the infant recorded during both the writhing and the fidgety periods of GMs. Infants diagnosed with a syndrome or intraventricular hemorrhage grade II-IV according to Papile (Papile, Burstein, Burstein and Koffler, 1978) were excluded. Ultimately, 30 participants and 60 video recordings were included. The study protocol was

approved by the ethics board of the Children's Hospital of Fudan University. Written

informed consent was obtained from parents/legal guardians of all participating infants.

Video recordings

All infants were placed supine on a standard bed/mattress wearing a nappy and a bodysuit to

make them comfortable. All recordings were performed during active wakefulness using a

stationary digital video camera (Panasonic HX-DC2, resolution: 1280x720). To ensure

camera consistency, the camera was placed at the foot end of the bed/mattress and the set-up

was standardized for all video recordings. Both assessment techniques were based on video

recordings trimmed according to Prechtl's GMA methodology (Einspieler et al., 2004).

Observation of general movements

GMs were classified by two certified observers according to Prechtl's method of GMA

(Einspieler et al., 2004), both of whom had successfully completed GM Trust training

courses. One observer, who had not been involved in the recruitment of the participants, was

blinded to the infants' medical histories. The two observers performed their assessments

independently. In case of disagreement, they re-assessed questionable videos together to

reach consensus. GMs during the writhing period were classified as normal if variable,

complex and fluent movement patterns were observed, and as abnormal if the subcategories

poor repertoire, cramped-synchronized or chaotic were applied. FMs were defined as normal

if present (N) and as abnormal if absent (FM-), sporadic (FM+/-) or exaggerated with respect

to speed and amplitude (Fa). Infants with GMs classified as cramped-synchronized (limb and

trunk muscles contract and relax almost simultaneously), chaotic (limb movements of large

amplitude that occurs in a chaotic order) or with abnormal FMs (absence of FMs/sporadic

FMs that is interspersed with long pauses/FMs that is exaggerated with respect to speed and amplitude) were excluded from the study because their movement patterns clearly differ from infants with normal movement patterns that was needed for this study.

Computer-based video analysis of general movements

The video analysis software was described in detail in previous papers (Adde et al., 2009; Adde et al., 2010; Adde et al., 2013; Valle et al., 2015). The videos contain 25 frames per second with 1280 x 720 pixels. By subtracting subsequent frames in the video stream (*frame differencing*), the number of pixels that change between frames is calculated to create the "motion image." A motion image thus represents the motion between two video frames (Jensenius, 2013), which allows us to export quantitative data based on pixel values in the motion image. A motion image with a value of zero indicates that no movement occurred between the frames; one with positive values represents movement (Adde et al., 2009; Adde et al., 2010). All videos in the present study were cropped so as to remove any movements by sources other than the infants (e.g. interfering parents), leaving for analysis only a window with the standard bed/mattress and the infant.

To visualize entire movement sequences, we used *motion average images* and *motiongrams* exported from the videos, with infants represented in a frontal view so as provide us with coherent spatial and temporal movement information, respectively (Jensenius, 2013). A motiongram can be seen as a representation of the motion image. Each motion image is averaged to a one-pixel-wide or -tall matrix and plotted over time. The results are displayed either in a horizontal or a vertical motiongram. An average image, as shown in Figure 1, combines all motion images into a single display, thus giving an impression of the spatial

distribution of motion during the entire recording. A horizontal motiongram like the one in Figure 2 shows the temporal characteristics of an infant's movements during the writhing and fidgety movement periods.

Quantitative variables used in previous studies (Adde et al., 2009; Adde et al., 2010; Adde et al., 2013) were derived from the motion image by means of computer-based video analysis. *Quantity of motion* (Q) is the calculated sum of all pixels with positive values (i.e. active pixels) in the motion image divided by the total number of pixels in the image. The mean and standard deviations of the quantity of motion (Q_{mean}, Q_{SD}) were used as independent variables in further statistical analysis. The *Centroid of motion* (C) is the spatial center of pixels with positive values in the motion image. This variable reflects the center point of the infant's total movement; its position changes continuously during a video sequence. The mean value and standard deviation of the centroid of motion in horizontal (X) and vertical (Y) directions were calculated (Cx_{mean}, Cy_{mean}, Cx_{SD}, Cy_{SD}). The variability of the centroid of motion (C_{SD}) was derived from the Cx_{SD} and Cy_{SD}. Evenly distributed movements in all body parts and all directions find expression in a low variability of the centroid of motion (C_{SD}), regardless of the amplitude of movement. Unsteady limb movements (i.e. uneven lateral activity of the upper and lower limbs) will typically yield higher C_{SD} values.

<u>Statistics</u>

Data were analyzed using SPSS Statistics version 21.0 (IBM SPSS Statistics, Chicago, IL, USA) and variables were examined for normality using the Kolmogorov-Smirnov test. Because all values were small and contained many decimals, they were multiplied by 1000. To correct for the increase in body size between the writhing and fidgety movement periods,

all variables were normalized for trunk area (TA), which was calculated by multiplying the trunk length by the trunk width measured from the video image, and given in cm^2.

The computer-based variables showed normal distribution, and parametric statistics were employed. The estimated group means for infants assessed during the writhing and fidgety movement periods were calculated. Between-group differences were determined in a paired sample *t*-test, and variable differences were reported including percentages.

RESULTS

Observation of general movements

Three infants with abnormal GMs during the FMs' period – two with sporadic FMs and one with absent FMs – were excluded from further analysis. Hence, the final analysis sample comprised 54 video recordings of 27 infants, all of whom were classified as normal during the FMs' period (all infants with a poor repertoire of writhing movements had normalized by the period of FMs). A poor repertoire has a very low predictive power of abnormal outcome in such cases (Einspieler et al., 2004), so all infants were included for further analysis. During the writhing period, 12 videos were classified as poor-repertoire, 15 as normal and none as cramped-synchronized or chaotic. The observers disagreed on one (1.8%) video clip but then discussed it and reached consensus.

Participants and video recordings

The study group consisted of 20 boys and 7 girls, with a mean gestational age of 32 weeks (SD 2.7, range 27-36) and a mean birth weight of 1790 grams (SD 430g, range 1185-2700g). Table 1 shows neonatal morbidities in all participating infants. The mean duration of the

edited video recordings used for observation and computerized GM assessment was 5

minutes (range 3-10 minutes and 3-11 minutes for the periods of writhing and FMs,

respectively).

Insert table 1 about here

Computer-based video analysis of general movements

Table 2 shows the infants' motion image variables during the writhing and fidgety movement

periods. All variables showed lower values in the period of FMs than during that of writhing

movements. The difference was statistically significant in all centroid-of-motion variables (*p*

<0.05). The biggest difference was recorded for the mean centroid-of-motion variables of

movements in horizontal and vertical directions, with 12.9% and 16.3% lower values during

the period of FMs, respectively. The variability of the centroid of motion (C_{SD}) was 7.5%

lower during the FMs' period than during the writhing movements' period of GMs (p=0.004).

There were no significant differences in any of the motion image variables between infants

with abnormal (i.e. poor-repertoire) GMs and those with normal GMs during the writhing

movements' period.

Insert table 2 about here

DISCUSSION

In the present study we identify quantitative movement differences between the writhing and

fidgety GM periods in preterm infants assessed by computer-based video analysis. In

consistence with our hypothesis, the computer-based video analysis showed the variability of

12

the centroid of motion (C_{SD}) to be low, with small and variable movements evenly distributed across the body – a typical FM pattern.

The random selection of infants was based on an estimated low-to-moderate risk of adverse development. The study was designed to explore the developmental trajectory of previously described, computer-based motion variables; its results cannot be extrapolated to a specific patient group. Although the present study included only 27 infants, results were highly significant and consistent with our hypotheses which was based on expert knowledge of GMA. Furthermore, results were consistent across all parameters related to the variability of the centroid of motion. Lower mean and variability of the centroid of motion in the horizontal and vertical directions (Cx_{mean}, Cx_{SD}, Cy_{mean} Cy_{SD}) during the FMs' period suggest smaller and variable movements distributed evenly across the body. In a previous study, the variability of the centroid of motion (C_{SD}) showed lower values in infants with normal FMs than in infants with abnormal FMs (Adde et al., 2009). This was also the case in a study predicting CP in high-risk infants, which found lower C_{SD} values in non-CP children than in CP children (Adde et al., 2010). The frequent changes in the small movements of the neck, trunk and limbs in all directions, typically observed during the period of FMs, results in variable movements distributed evenly in the motion image (Adde et al., 2009; Adde et al., 2010; Adde et al., 2013). Infant movement patterns with hands and feet tucked in towards the midline, which is more typical of the FMs' period than of the writhing movements' period, could potentially contribute to a low C_{SD} value, but in most cases this behavior occurred only sporadically throughout the video, which would clearly not have had a significant effect on the C_{SD} value. This is supported by the motion average image in Figure 1, where movements

with small amplitudes (darker grey scale close to the infant's body) are more common during the FMs' period than during the writhing period.

Insert figure 1 about here

Insert figure 2 about here

The motiongrams in Figure 2 also show that FMs are continuous over time across all body parts and in all directions (lower panel), which does not apply to writhing movements (upper panel). There were no differences between the writhing and FMs' periods with regard to the mean and variability values of the quantity of motion (Qmean, Q_{SD}). The quantity-of-motion value in our sample represents FMs as well as concurrent movements such as wiggling-oscillating, swiping and kicking movements, which occur in both GM periods (Einspieler et al., 2004). Figure 2 thus indicates that the differences between FMs and writhing movements apply to movement characteristics other than the amount of movement quantified by Qmean and Q_{SD}.

One limitation of our computer-based video analysis is that it mainly reflects spatial aspects of general movements but does not include specific temporal characteristics, which are just as likely to be relevant for an accurate computer-based classification of GMs. The moderate speed, variable acceleration and waxing and waning intensity of FMs are complex phenomena recorded and interpreted by the GM observer during Gestalt perception. In order to include temporal aspects of FMs in the computer-based video analysis it is necessary to continue searching for additional movement variables that reflect temporal changes in GMs. It could also be argued that the inclusion of infants with abnormal (poor repertoire) GMs during the writhing movements' period is a limitation to our study, even though they have

low predictive value of later adverse neurological outcomes (Einspieler et al., 2004). Our findings show no significant differences between the motion image variables of normal and poor-repertoire infants during the writhing GM period. This may indicate that other movement variables and/or more advanced 3D spatial and temporal analyses are required to further differentiate between movement qualities during the writhing GM period. Our study design of evaluating motion image variables by comparing writhing with FMs should of course be taken further by comparing present and absent FMs as well as the temporal organization of FMs. Hence, the relationship between variables used in the present study and typical characteristics of GMs should be further explored in more detail.

Despite the mentioned limitations we believe that the use of regular 2D video camera recordings and computer-based video analysis without additional instrumentation and with limited need for user expertise are obvious advantages over other studies (Karch et al., 2010; Karch et al., 2012; Kim, Wochner, Karch and Hadders-Algra, 2009; Kanemaru et al., 2013; Marcroft et al., 2015). The availability, cost-effectiveness and moderate need for expertise of video recordings in combination with computer-based software are compelling reasons for making the method available in all kinds of clinical settings.

Conclusion

We used our computer-based video analysis method to investigate direction and amplitude of FMs. The variability of the centroid of motion in infants' movements derived from video recordings was significantly lower during the FMs' period than during the writhing movements' period, representing small and variable movements evenly distributed across the body. Further studies are needed, however, to explore important temporal characteristics of

FMs based on video recordings to gather new movement variables and improve the accuracy of computer-based video analysis in the assessment of FMs and prediction of CP.

Declaration of interest

Acknowledgements

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