Assessment of the validity of parameters describing temporal and spatial characteristics of spontaneous infant activity in the period of fidgety movements

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Research article

Keywords: infant, computer-aided motion analysis, spontaneous movements, pediatric neurology, biomedical engineering

Posted Date: August 13th, 2020

DOI: https://doi.org/10.21203/rs.3.rs-47505/v1

Abstract

Background: The assessment of spontaneous activity of infants is of fundamental importance to the diagnosis and prediction of abnormal psychomotor development in children. Comprehensive and early diagnosis allows for quick and effective treatment and therapy. Subjective methods are based on the knowledge and experience of the diagnostician. The lack of objective methods to assess the motor development of infants makes it necessary to search for solutions for reliable, credible, and reproducible assessment expressed in numerical or pictorial terms. This study discusses the possibilities of pictorial standardization and optimization of measurable infant behavior based on video recordings.

Methods: The authors attempt to perform computer analysis of spontaneous movements depending on the left, right, and front head position. The study was based on data of 26 healthy infants aged 7 to 15 weeks, with three infants included in an in-depth analysis. The selected films represented the input data for the parameters used as the author's temporal and spatial characteristics describing the global movements of the upper and lower limbs. The obtained videos were used as the input data for the algorithm of automatic detection of characteristic points using the OpenPose library.

Results: The following movement characteristics were analysed: Factor of Movement's Area (FMA) ("amount of movement in the movement"), Factor of Movement's Shape (FMS) ("circularity" or "ellipticity" of the movement), Center of Movement's Area (CMA) ("inward and outward" and "up and down" movements). Preliminary analysis of the videos showed that the activity of the limbs, especially the upper limbs, may depend on the position of the head.

Conclusions: The movement behavior of the infants varies in terms of the range and quality of movement, depending on age and head position.

Background

The problem of objective assessment of the motor activity of infants has been the subject of numerous studies. The proposed solutions focus on measuring tools that can be used in a way that least disrupts the child's natural activity. The assessment systems presented in the publications are aimed at recording movement using numerical parameters and validating the obtained data. Most researchers propose to assess the activity of infants by recording spontaneous movements based on the trajectory of movement using markers located in different points on the body (Ciuraj et al. 2019; Karch et al. 2008).

The presented measuring tools include those that use three-axis accelerometers during the examinations to measure the speed and acceleration of movements in the three-dimensional space. The time-series data for acceleration are subject to linear and non-linear analysis. They provide information on the character of the movement, i.e. its direction, area, speed, and predictability, reproducibility, and dynamics. The measurement of the acceleration may concern both the upper and lower limbs (Heinze et al. 2007) or apply to upper limbs only (Ohgi et al. 2008).

In addition to accelerometers, magnetic sensors have also been in use in diagnostics. They have been applied in the computer-aided analysis of general movements. They were used to develop a system that tracks the movements of the infant's upper and lower limbs during spontaneous activity (Philippi et al. 2014). Infant movements were monitored using magnetic minisensors placed on the infant’s body in two configurations: on the upper and lower limbs of the same side of the body and on the upper limbs. Computer analysis of infant movements allowed for the assessment of the position of limbs in all degrees of freedom of movement and the identification of the complexity and variability of movements. The method also made it possible to determine the kinematic characteristics typical of normal and abnormal general movements.

Another group of diagnostic methods is based on the use of video cameras to track infant movements. In one study, measurable results of the assessment were obtained with the Vicon 370 system, consisting in monitoring the movements using 6 cameras (50 Hz), with a set of markers (reflective stickers) distributed on the body of the diagnosed infant (Meinecke et al. 2006). The system allows for the evaluation of numerical movement parameters such as speed, body segment acceleration, and differences in these parameters between the right and left sides of the body.

The advantage of using these methods is their objectivity in the assessment of movements and independence from the subjective skills of the observer (Ciuraj et al. 2019; Kieszczyńska et al. 2018). Computer-aided analyses allow for tracking all kinds of movements both on a single plane and in the three-dimensional space. The data on rotation, elongation, and bend obtained with the digital objective analysis represent information that cannot be captured by the investigator during optical observation by the researcher. They are based on the specific measurement and numerical data. The results collected may be further analyzed and compared. The described methods of objectivization of infant’s movements may, however, have some disadvantages. There is a view that the examination of movements using sensors can modify the postural system of infants (Karch et al. 2008). Installing accelerometers or markers on the infant's body can directly modify its motor activity by provoking intuitive attempts by the child to get rid of the foreign body from the limb. The tests are additionally connected with the necessity to use specific premises and apparatus that ensure the conditions which are similar to laboratory settings and completely different from friendly home environment, which may also have a measurable effect on the quality of performed movements. The use of these tools also requires the use of specialized measuring equipment, which is not generally available and needs to be operated by specialized personnel.

The diagnostic scales used in clinical practice are based on the subjective evaluation of the diagnostician and, consequently, on his or her experience and knowledge (Ciuraj et al. 2019). The most popular scales include Test of Infant Motor Performance (TIMP) (Nuysink et al. 2013), General Movements Assessment (GMA) (Einspieler & Prechtl 2005), Vojta’s kinesiological diagnostics (Gajewska et al. 2006), Alberta Infant Motor Scale (AIMS) (Piper et al. 1992), Harris Infant Neuromotor Test (HINT) (Harris et al. 2010), Dubowitz Score (Dubowitz et al. 2005), Movement Assessment for Infants (MAI) (Rose-Jacobs et al. 2004), Peabody Developmental Motor Scales (PDMS) (Maring & Elbaum 2007), Structured Observation of Motor Performance (SOMP I) (Montgomery et al. 2017; Johansen et al. 2017). The described situation inspires the search for an objective, non-invasive, and effective measurement system (Ciuraj et al. 2019; Kieszczyńska et al. 2018). It seems that the digital analysis of infant movements recorded by a video system meets the above criteria.

In conclusion, the disadvantage of subjective scores is the lack of reliable reproducibility of the assessment, whereas the disadvantage of objective tests using sensors is interference in natural activity. With the need for the search for new diagnostic solutions with the use of information technology, the assessment of the model of infant observation was made, using the condition of head rotation to the left, to the right, and the front head position. Based on the analysis of the point movement on the plane, the question was asked whether the head position can affect the observation results. Given the importance of the subject matter of the present study and the dynamically developing opportunities for computer-aided neurodiagnostics of infants, each proposed model and algorithm should be subjected to the process of determination of the extent to which it reflects the actual system. This study identified temporal and spatial characteristics based on the video recording of infant movements, which can be used to create parameters describing the movement.

Methods

The study was approved by the Biomedical Research Ethics Committee (No

5/2018) and in accordance with the Declaration of Helsinki.

Participants

The study examined infants (n = 26) aged from 7 to 15 weeks in the period of fidgety movements (FM) (Einspieler et al. 2016). The inclusion criteria were: the full-term infants (38–41 Hbd) and single pregnancy without negative medical history and worrying symptoms. All the infants received the Apgar score of 10. The information about the infants was coded in the form of the letter K with the examination number assigned to the infant. Three participants were finally identified for observation (Table 1).

Table 1
Biometric data

	K013	**K019**	**K005**
Age (week)	11	9	14
Birth weight (gr)	3280	3620	3350
Birth length [cm]	53	57	56
Recording time (mm:ss)	20:55	20:01	18:04

Testing Procedure

The recording was made using a portable video recording system in the patient's home. The stand consisted of a lying place that met the standards of hygiene and safety. The surface was soft, washable, with side stops. The stand frame was stable, with dimensions of 1 m x 1 m x 1 m, equipped with places for mounting motion recording devices (video cameras). The equipment used in the examinations did not pose any threat of radiation or other energy that could in any way affect the safety of the child under observation. Videos were recorded in FullHD 1080 resolution (1920 × 1080, 60 fps). The platform was placed on a stable and adequately illuminated ground. The position of the child during the examination was free, lying on his or her back, without any distractions. The child did not cry during the recording. The examinations were always performed at the same time of the day, after sleeping and feeding. The recording was repeated three times, for about 20 minutes (video). The recording time depended on the circadian rhythm of the infant, with the decision on the time made by the parent. Two models of recording were used. Model 1: the first examination on the first day, the second examination on the first day after the first nap, the third examination on the next day. Model 2: the first examination on the first day, the second examination on the second day, the third examination on the second day after nap. Quiet was ensured for each infant, whereas the parent was in the room, and, if the child cried, the examination was stopped immediately.

Analysis

Preliminary analysis of the videos showed that the activity of the limbs, especially the upper limbs, may depend on the position of the head. The three children with the longest time of the right, left or front head positions were selected for the presentation of the results.

The position of the head at a given moment was automatically determined by the position of the nose in relation to the body axis. The threshold of the transition from looking forward to looking sideways was defined based on the observation as 30 pixels. Next, the samples were summed up for a specific state and each of the three values was divided by the total number of signal samples. This yielded the percentage of frames with a given head position. This allowed for the choice of three recordings that represent each of the three positions (Fig. 1).

Objective Description of Movements

The collected recordings were subjected to the procedure of removing the distortion based on the camera model obtained by calibration with a chessboard pattern. Next, areas of interest represented by the parts containing only the examined child were chosen from each recording. The obtained videos were used as the input data for the algorithm of automatic detection of characteristic points using the OpenPose library (Cao et al. 2018). The locations of the points were preprocessed to reduce the effect of incorrect detection. Points with low values of the certainty index were replaced by previous locations. The Savitzky-Golay filter was applied to reduce high-frequency vibrations. The proposed movement parameters are expected to be used to describe the mobility of the limbs. Therefore, in order to reduce the effect of the whole body movement of the child, the locations obtained for individual frames were shifted in such a way that the point determining the location of the neck did not change over time (Marchi et al. 2019). Next, the points were rotated in such a way that the axis of the body was vertical to the image.

This study attempted to obtain a quantitative description of the range of movement, its position and orientation through the parameters of the ellipse circumscribed about the trajectory from a selected time interval. The ellipse determination algorithm consists in calculating the eigenvectors and eigenvalues of covariance matrices of the coordinates of trajectory points, allowing for the determination of their scatter in two perpendicular directions. In order to reduce the effect of occasional movements deviating from the general area of their concentration, an additional procedure was developed before circumscribing of the ellipse. The algorithm for reducing such outliers was based on the interquartile distance of each trajectory point from the mean (Doroniewicz et al. 2020). The effect of trajectory density on the obtained ellipse was eliminated by removing, for each point, all points located within the distance of 5 pixels. The resulting ellipse allowed for the numerical description of the range of movement by calculating the surface area. The averaged position of movement concentration determines the position of the center of the ellipse. The Factor of Movement Shape (FMS), which is the quotient of the length of the short and long axis of the ellipse (Fig. 2), allows for the description of the general directions of the movement and its global character.

Since the analysis was performed based on the images, the obtained parameters of the surface area and the location of the center are expressed in pixels. The independence of the results from the image domain was achieved by the developed normalization procedure, in relation to the numerically determined length of the analyzed limb. The surface area of the ellipse was divided by the surface area of the circle whose radius was the distance between the shoulder and wrist (Fig. 3). The resulting factor was termed Factor of Movements Area (FMA). The location of the center of the ellipse was described using the coordinate system associated with the corresponding shoulder for the upper limbs and hip for the lower limbs. The unit of such a coordinate system is provided by the automatically determined length of the analyzed limb (Fig. 4). The normalized position of the center of the ellipse is termed Center of Movements Area (CMA).

The determination of the value of each characteristic was carried out for a 3-minute time period. Next values were obtained by changing the analyzed range by 10 seconds. This allowed for obtaining good resolution of the parameter value variation graphs over time.

Results

Factor of Movements Area (FMA)

The parameter can be colloquially defined as the amount of "movement in the movement", and it is worth noting that spontaneous movements were observed rather than the functional length of individual muscles (Fig. 5). The infant who controlled the head in the central position was 15 weeks old at the time of observation, whereas the infant in the chart on the left was 9 weeks old and the infant on the right – 11 weeks old. In the experiment, younger infants showed more activity (greater % FMA, more "elliptical” movements), while those older were characterized by greater maturity, especially in the stability-mobility relationship, where the amount of movement is slowly replaced by its quality (lower % FMA, more "circular" movements). As "less is not worse", perhaps this is the moment when infants start to reach the next stage of development, whereas the three weeks is a significant difference in age. This is a characteristic that certainly needs to be further researched, especially on a larger population.

Furthermore, a difference in the movements of upper and lower limbs was observed. In all the observed patients, the activity of the upper limb on the occipital side was much higher. The general range of surface area values (Y axis) is similar for all three cases.

Factor of Movement's Shape (FMS)

This factor defines the shape of the surface in which the movement takes place. Two types of shape of the movement surface were distinguished - a circle and an ellipse. Larger values mean a greater circle and smaller ellipse (Fig. 6).

It was observed during the experiment that on the occipital side, the upper limbs showed higher FMA and thus FMS was more elliptical, whereas on the facial side, FMA was smaller and FMS was more circular. The facial side showed more circular movement characteristics, whereas the occipital side was characterized by more elliptical movements.

Analysis of the lower limbs revealed that the FMA values were similar, both on the facial and occipital sides.

On the loaded side, i.e. better-stabilized side, the movements of the upper and lower limbs on the same side yielded a circle-shaped surface.

The more movement area on the occipital side, the more elliptical the shape of the movement. Similarly, the less movement area on the facial side, the more circular the shape.

Theoretically, it can be assumed that circular movements are an expression of greater maturity, and this was confirmed in the case of infant K05, who was characterized by the control of the head in the central line of the body while also showing circular movements (higher FMS value). Little movement area (FMA) and more circular movements (FMS) were observed in this infant.

Perhaps the movement circularity for the upper limbs is linked to the greater component of supination during flexion and extension, whereas for the lower limbs, greater pronation and abduction were observed during kicking.

In K05, FMS in the lower limbs was substantially more elliptical compared to K013 and K019. There is no explanation for this pattern at the moment.

Center of Movement's Area (CMA)

The greater the value of the CMA, the more outward the movements. Furthermore, the closer it gets to zero, the more inward movements are observed (Fig. 7). An analogous analysis was made with respect to the vertical axis (Fig. 8).

Discussion

The qualitative analysis of movements, especially the spontaneous movements of infants, is a source of many difficulties for researchers around the world. Computer analysis of general movements allows for the computation of the positions of the limbs in all degrees of freedom of movement. The movement is described repetitively and quantitatively. It is possible to identify the complexity and variability of movement, which are critical for spontaneous movements. The objective analysis of infant movements can provide valuable support for the decisions made by both doctors and for physiotherapeutic practice. The general motion analysis, which was first described by Prechtl et al. (1997) is performed based on video recordings from the first months of an infant's life. Specificity, sensitivity, and positive and negative prediction values proved to be excellent for the prediction of motor dysfunctions (Groen et al. 2005). One of the key parameters for qualitative assessment of general movements is time variability: infants who present normal movements produce constantly new movement patterns, while abnormal movements have a stereotypical quality (Hadders-Algra 2001). The above-mentioned authors proposed the first simple example to illustrate the differences between normal and abnormal movements.

The normal infant movements are smooth, elegant, and varied. They include smooth movements of the upper body, head, and limbs. Variety concerns all the characteristics of the movement, i.e. movement patterns, the sequence of including individual body parts into the movement, and their amplitude and speed. Furthermore, normal movements include components of rotation, pronation, and supination in the joints related to these movements (Einspieler & Prechtl 2005).

Abnormal movements are monotonous, lacking a smooth transition between individual body parts and uncoordinated. The movements are not different from each other and are stereotypical. Therefore, there is a lack of variety in terms of movement patterns, the sequence of appearance, amplitude, and speed (they are too fast or too slow). Furthermore, they do not contain any component of rotation (Prechtl 2001).

Doroniewicz et al. (2020) attempted to identify specific characteristics of features. The selected parameters of spontaneous infant movements were measured and quantitative indicators describing these movements were obtained. Consequently, an optometric prototype of a model for the evaluation of spontaneous movements was developed. The proposed model for the evaluation of spontaneous movements of infants ensures the objectivization of evaluating the infant development based on quantitative factors expressed as numerical values. This makes it possible to quantify the results and reduce diagnostic errors in the evaluation of motor functions resulting from different experiences of the examiners. Recording of the parameters of infant movements in the form of quantitative factors will allow for collecting information needed for: (1) the assessment of the initial functional status of the child, (2) setting the goals for the neurodevelopmental therapy, and (3) comparison of the initial and periodic examinations to properly conduct the therapy, continue the therapy and/or determine the time of completion of the therapy. In the above-mentioned study, the authors attempted to distinguish a set of characteristics allowing for an objective and quantitative description of various aspects of spontaneous infant movements. Basic kinetic parameters (speed and acceleration) were analyzed. The other proposed parameters were aimed to characterize the range of movements (parameters of the ellipse circumscribed about the point trajectory) and identify the location of its highest density (mean value) for a specific time interval (in this paper, the analysis was conducted for 3-minute recordings).

The main focus of the study was on the analysis of individual characteristics of movement: Factor of Movement's Area (FMA) ("amount of movement in the movement"), Factor of Movement's Shape (FMS) ("circularity", "ellipticity" of the movement), Center of Movement's Area (CMA) ("inward and outward" and "up and down" movements) (Electronic Supplementary Material). The quantitative assessment of qualitative aspects of spontaneous infant movements was presented. Temporal and spatial characteristics were identified based on the video recordings of infant movements.

Application

The parameters presented in this study may contribute to the development of a reliable tool for the assessment of the quality of movement independent from the experience of the examiner and from the potential interference in the spontaneous activity of the examined infant.

Abbreviations

FMA Factor of Movement's Area

FMS Factor of Movement's Shape

CMA Center of Movement's Area

FM fidgety movements

Declarations

Ethics approval and consent to participate

The study was approved by the Biomedical Research Ethics Committee, Katowice, Poland (No 5/2018) and in accordance with the Declaration of Helsinki.

Written informed consent was obtained from the parents of the children to participate in the study.

Consent for publication

Written informed consent for publication was obtained from the parents of the children.

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

Funding

Not applicable.

Authors' contributions

AM, MM, ID developed the concept of the project and diagnostic assumptions. AA, KK conducted medical analysis, inference and neurodevelopmental interpretation. AWM, DL developed measurement assumptions and implemented algorithms. RM made the methodology of the measurement stand. MB performed inference, mathematical algorithms and statistical processing. A critical review and evaluation of the work was carried out by AM and AWM. All authors revised the manuscript for final submission and approved the final manuscript.

Acknowlegements

We acknowledge Doctor Joanna Wojcieszczyk-Bacia specialist in pediatrics and neonatology, Head Physician of the Neonatal Unit at Public Hospital in Piekary Śląskie for supporting the research.

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Figures

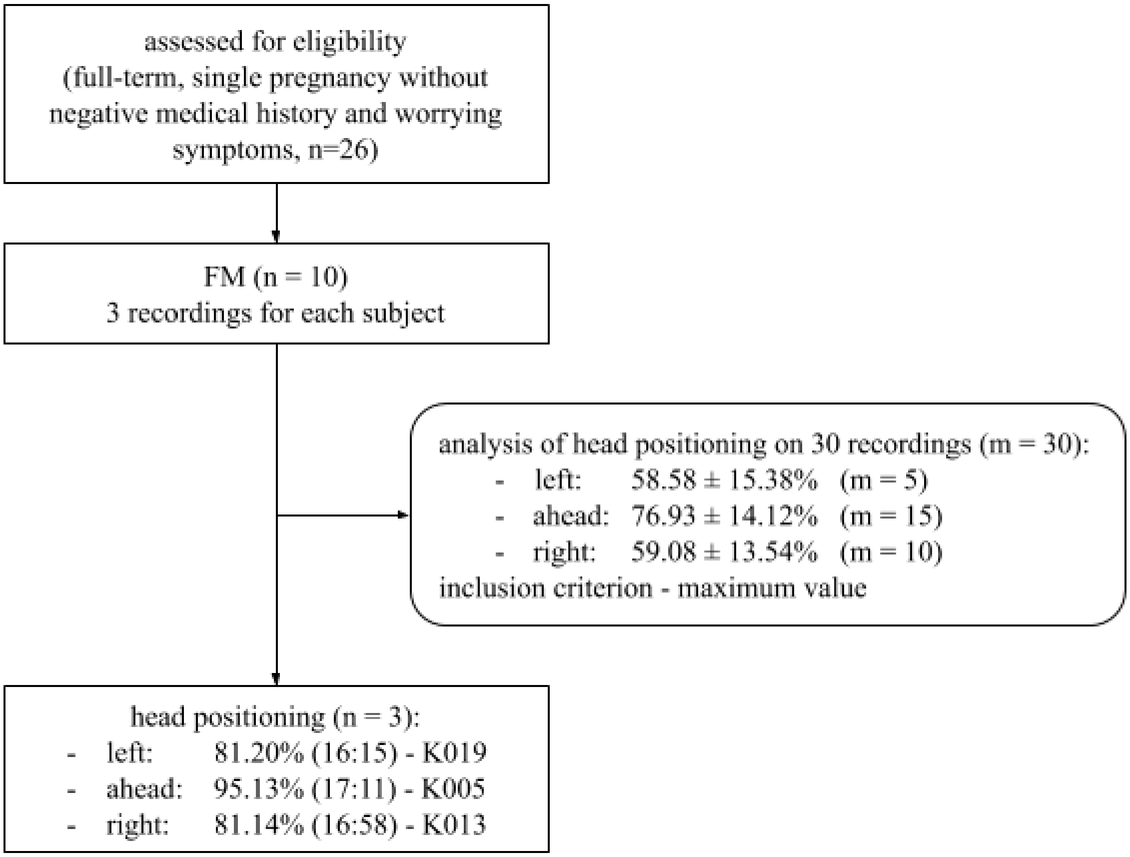

Figure 1

Flow diagram showing the procedure for choosing the recordings analyzed In the last block, in addition to the percentage value of the entire recording, the duration of each position was also specified (minutes:seconds).

Figure 2

Visualization of the short axis (a) and the long axis (b) of an ellipse describing the movement of the left upper limb. The FMS value was obtained by dividing the length of the short axis and the long axis: FMS = a/b

Figure 3

The maximum range of movement for the left upper limb (blue circle) and the ellipse circumscribed about the example trajectory (orange). The FMA value was obtained by dividing the surface area of the ellipse circumscribed about the trajectory by the surface area of the circle defining the maximum range of limb movement.

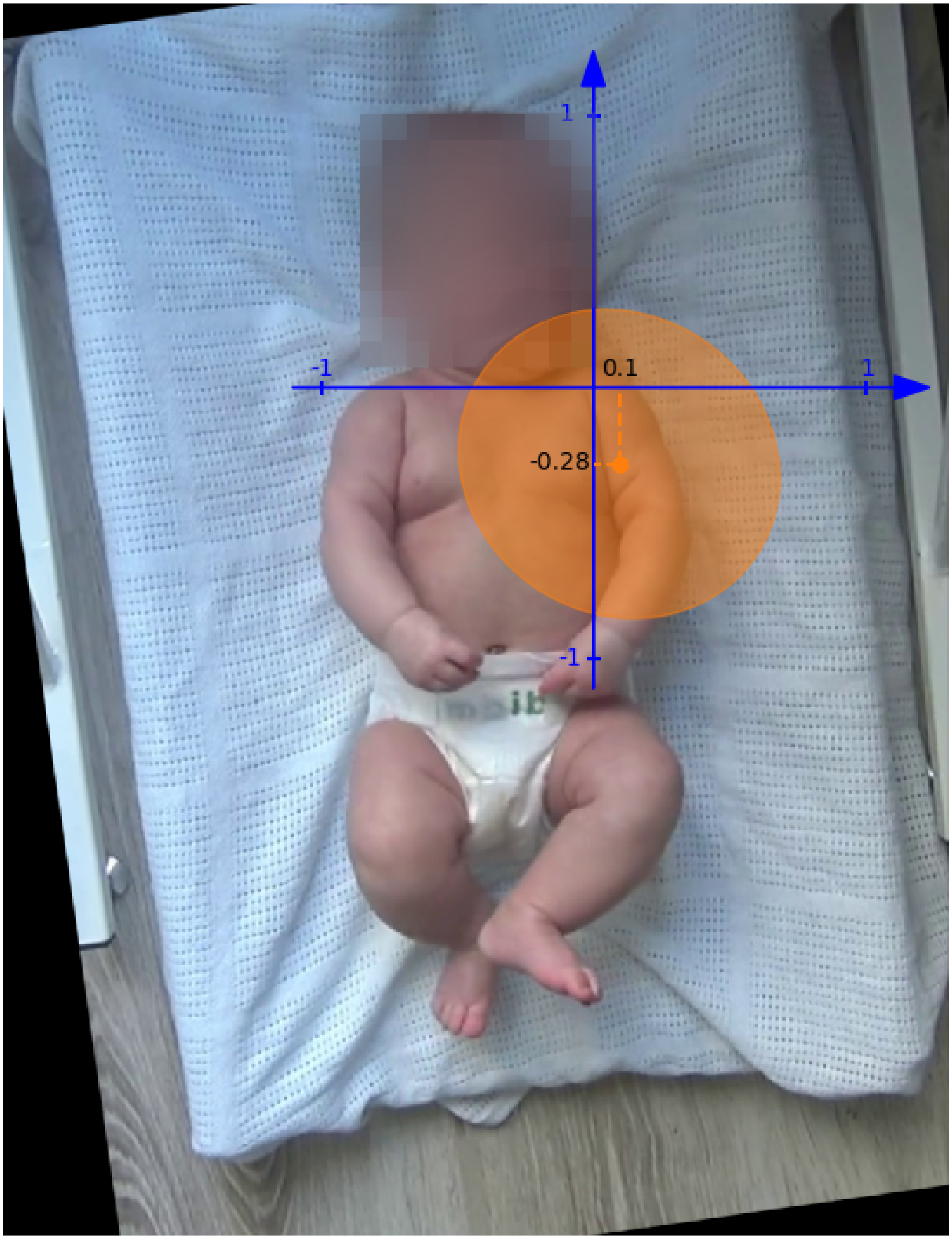

Figure 4

Visualisation of the location of the center of the ellipse in the coordinate system related to the position of the shoulder, normalized in relation to the length of the limb. The CMA contains two components determining the location relative to the shoulder (vertical and horizontal).

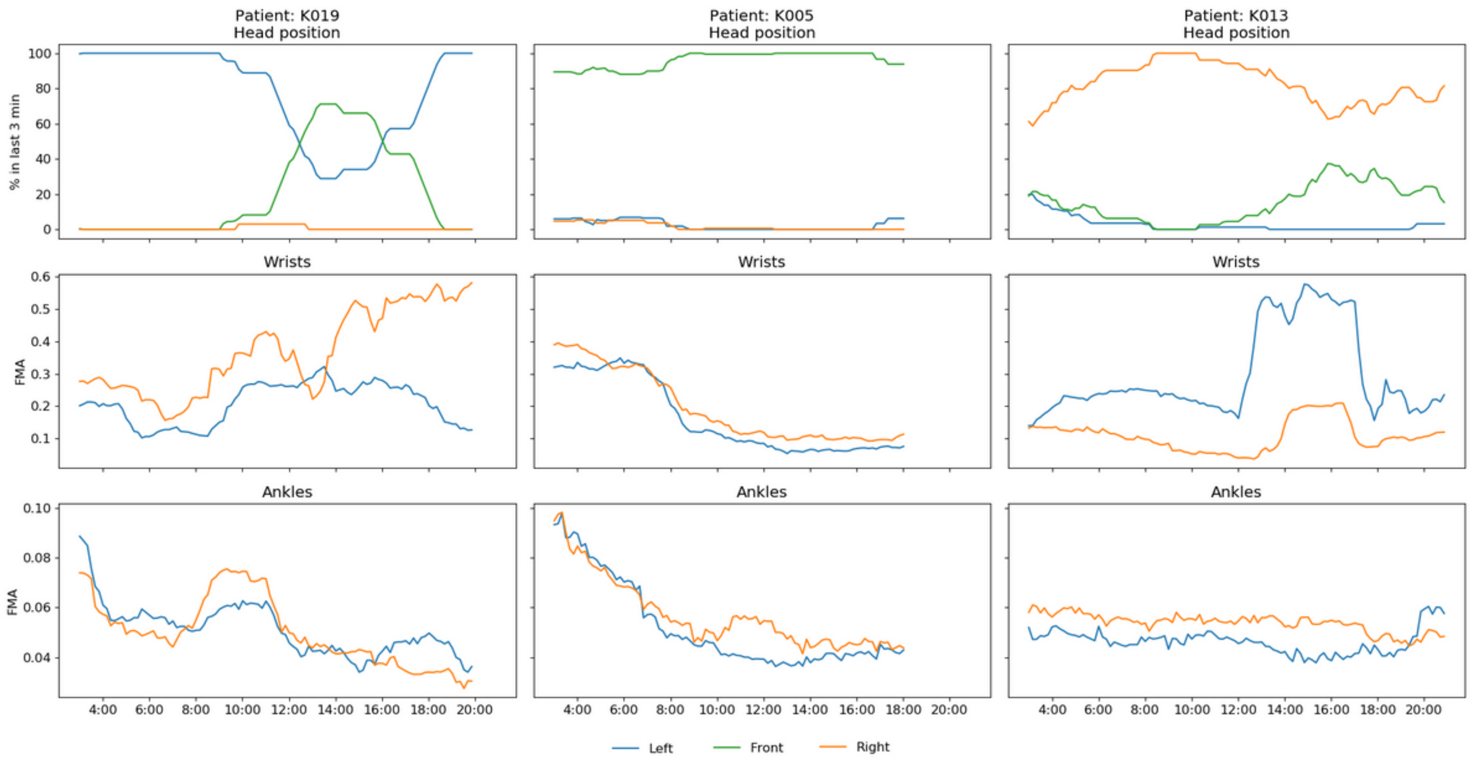

Figure 5

Temporal change in Factor of Movements Area [%] of upper and lower limbs for 3 selected patients. The upper graphs in each column show the percentage values of the individual three positions of the head in the analyzed period.

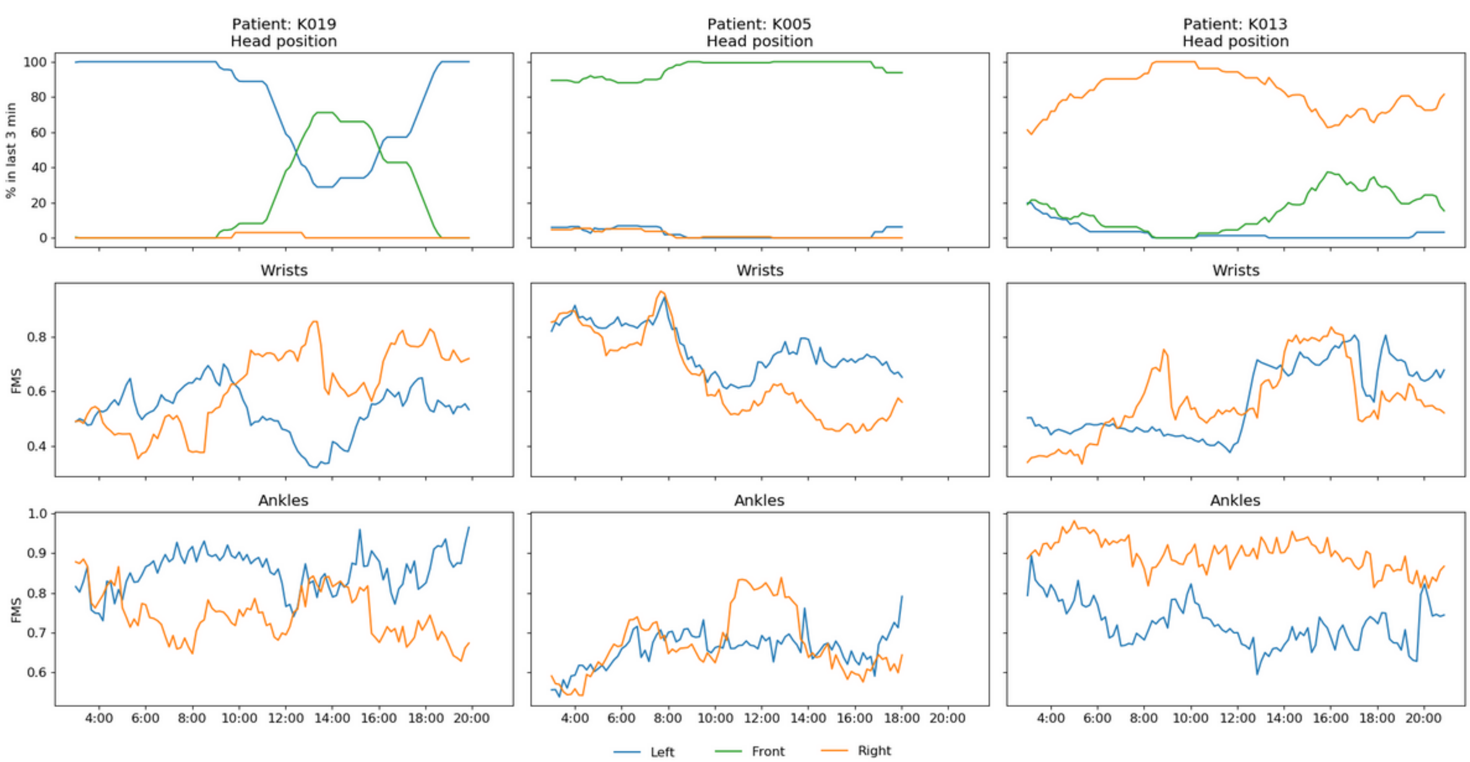

Figure 6

Temporal change in Factor of Movements Shape [%] determined for the upper and lower limbs for each selected patient.

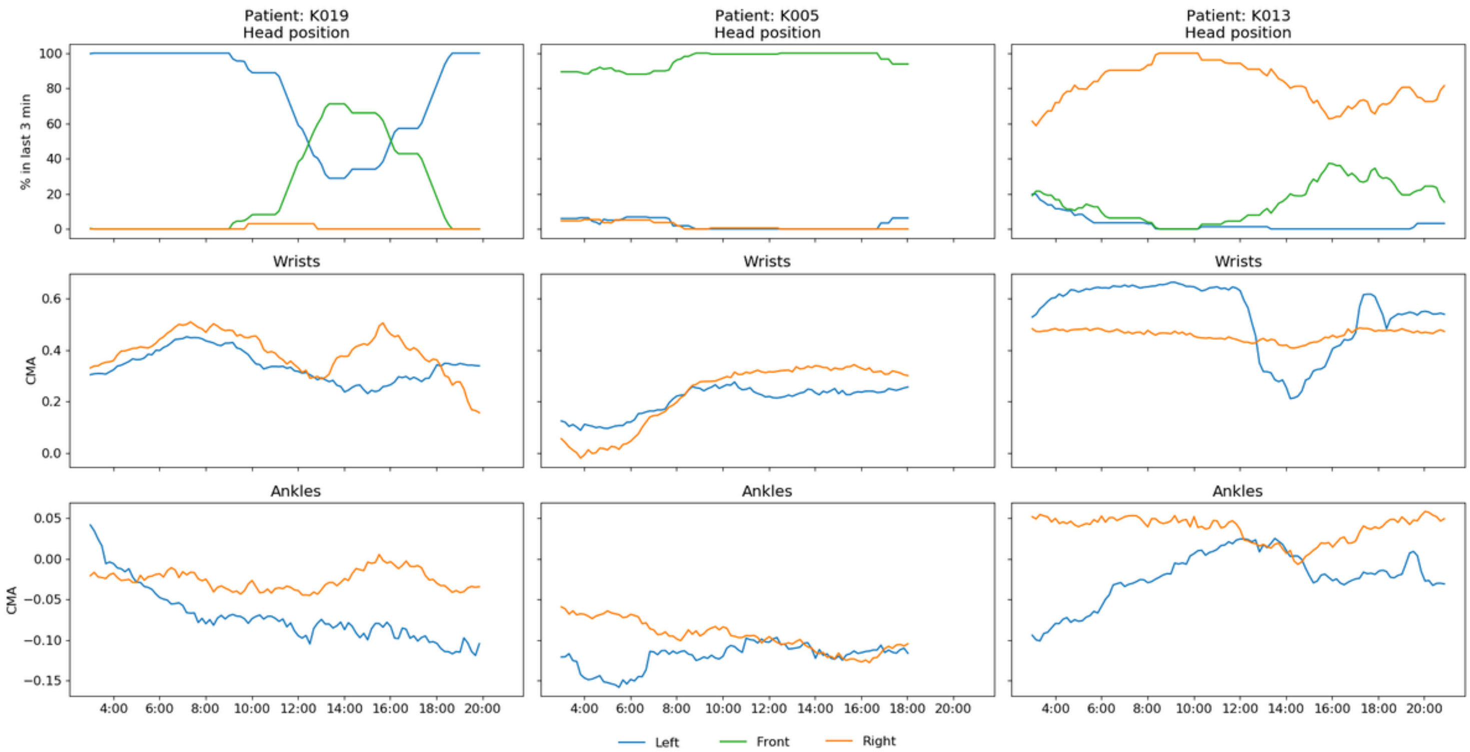

Figure 7

Temporal change in the horizontal component of CMA determined for the upper and lower limbs for selected patients.

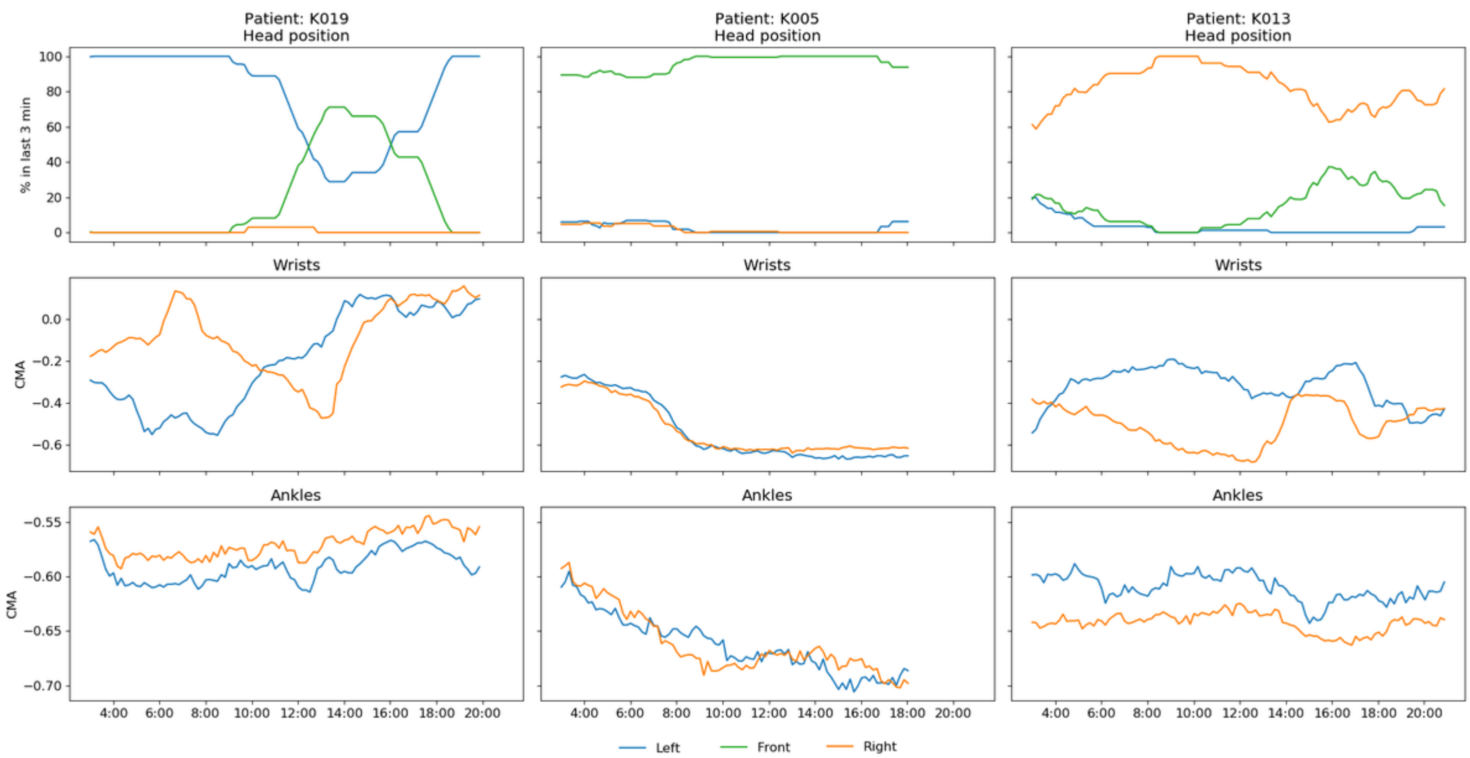

Figure 8

Temporal change in the vertical component of CMA determined for the upper and lower limbs for selected patients.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- ElectronicSupplementaryMaterial.mp4
- STROBEStatement.docx