Movement Analysis by Accelerometry of Newborns for the Early Detection of Movement Disorders due to Infantile Cerebral Palsy

F. Heinze[1], N. Breitbach-Faller[2], T. Schmitz-Rode[1], and C. Disselhorst-Klug[1]

[1] Chair of Applied Medical Engineering, RWTH Aachen University, Germany
[2] Social Pediatric Centre, Klinikum Esslingen, Germany

Abstract— **The most frequent cause of handicap in children is infantile cerebral palsy (ICP). To limit the consequences of ICP, physiotherapy should start as early as possible. Seemingly effective, the developed diagnostic strategies are not easily applicable in a clinical setting, possibly due to its subjective character. The objective approaches are too expensive and too complex to be established in pediatric offices to be used in daily routine. The developed methodology allows the objective diagnosis of developing movement disorders in newborns due to ICP and is able to be established in the daily routine of pediatric clinics. Features as low expenses, less time consuming and manageability make this system available for the screening of large numbers of infants. With an early diagnosis of ICP it is possible to minimize follow-up problems and thus to relieve the health care system and above all to significantly improve the quality of life for both the patients and their families.**

Keywords— **accelerometry, movement analysis, infantile cerebral palsy, movement disorders.**

I. Introduction

In the field of biomedical technologies, deployment of accelerometers is increasing. Since in the 1990s, it benefits from accelerometers research in other fields as for example the airbag release system development for the automotive industry [1]. Accelerometers provide even now sufficient quality and reliability for accessing the characteristics of movement disorders. Additionally they are inexpensive and sufficiently miniaturized for portable assessment [1,2]. Therefore, the accelerometers technology improves faster than other typically used tools for movement assessment [2]. There is a wide range of accelerometers application in assessing and quantifying human movements. Most implementations have concerned gait analysis. Furthermore, accelerometers have been successful introduced for reflex quantification and the monitoring of tremor in Parkinson's disease [1]. Summarizing the employment of accelerometers leads to improvements in the objective quantified assessment of movement disorders, their development, and therapy efficacy.

The most frequent cause of handicap and especially of movement disorders in children is infantile cerebral palsy (ICP). Approximately one out of 400 newborns is affected and the risk increases significant for pre-term newborns, depending on gestational age it can reach up to 10%. Today, diagnosis is based on visual observation of the spontaneous movements performed by the infant by physicians [3]. The so-called general movement assessment (GMA) has been described by Prechtl and colleagues in detail [4]. GMA is a subjective procedure based on the observer's acquired expertise and as such is influenced by subjective impressions. Although seemingly effective, GMA is not necessarily easily applicable in a clinical setting, possibly due to its subjective character [5], and there is an incipient demand for more objective methods [5, 6].

Meinecke et al. developed a full diagnosis support system to assist physicians with less experience in GMA. The existing diversity between healthy children and children with ICP can be described objectively by mathematical parameters, which are calculated out of the movement data gained from an optical motion analysis system. Basing on these parameters, it is possible to separate reliable the healthy from the affected group and to give a diagnosis support to untrained physicians [6]. But optical systems [5, 6] are too expensive to introduce them in pediatric practices for regularly use. In addition, the systems are not portable and still have the optical line-of-sight restrictions. The most of the extracted parameters of Meinecke and colleagues depend on acceleration or velocity of the newborns extremities. For example, out of the optimal parameter combination of eight parameters five parameters are concerning acceleration or velocity. Based on the prior observations and the improvements in accelerometers' technology, the aim of our study, was the development of a methodology which allows the objective and quantitative description of unconstrained spontaneous movement in newborns as described by Meinecke and additionally is able to be established in pediatric offices to be used in daily routine. Within the study, the relevant movement parameters have to be ascertained which can be obtained out of accelerometers signals of the infant limbs. These parameters quantitatively describe the differences between healthy and affected subjects. Together with the extracted movement parameters, the developed accelerometer system permits a reliable prediction of patients at risk for developing movement disorders even at the age of newborn babies.

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II. Methodes

A. Measurement system

The established assembly technology for accelerometers in human motion application is micromachining. The acceleration signal is generated by a physical method. Simplified, on a micro machined spring platform applied movable mass deflects in the presence of acceleration, which produces a measureable signal. The developed accelerometers based on the three axis micromachined accelerometer integrated circuit with a ±10g maximum range and a 120 mV/g sensitivity. With a measurement chain disposed downstream including high-pass filtering (cut-off frequency = 0.16 Hz) and AC/DC conversion (100 Hz sampling rate) the system achieves a resolution of 0.01g. Due to the high-pass filter the measurements are not affected by the gravity. The whole sensor weighs with cover only 0,001 kg and has a 12 mm diameter with a height of 8 mm (Figure 1). The cable, witch connects the sensors with the AC/DC converter, is light, high flexible and tear proof. The whole device of sensor and cable is water proof and sterilizable.

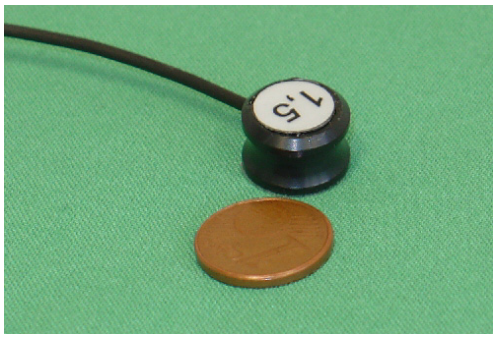

Fig. 1 Developed accelerometer

B. Participants

Twenty-three infants, nineteen healthy full-term (mean gestational age 39,6 weeks, standard deviation 1,4 weeks, 10 female, 9 male) and four high-risk pre-term (mean gestational age 29,25 weeks, standard deviation 4,2 weeks, 2 female, 2 male) infants took part in the study. All infants were clinically and neurologically examined. Pathology of the "at-risk" patients was ensured through ultrasound-based detection of cerebral haemorrhage or periventricular leukomalacia. Additionally, a few of the patients were screened using computer or magnetic resonance tomography. The healthy subjects of the control group were separated from "at-risk" patients by the criteria mentioned in [6]. To ensure, that subjects in the two groups, healthy children and children with ICP, were allocated correctly with respect to their diagnoses, all subjects' diagnoses were confirmed by a follow-up examination after 1 year in the run-up to this study. All affected children developed ICP; all healthy children were without pathological findings. Hence, all children were allocated correctly and the consistency of the two groups can be considered to be reliable. In the infants' first six months of life the development of spontaneous movements in healthy newborns and infants is divided into three post-natal phases: the writhing movements in the first eight weeks, the fidgety movements starting around six weeks after birth lasting till the twentieth week and finally the voluntary movements starting around the thirteenth post-natal week [4]. Therefore, measurements were carried out around the first, the third and the fifth months of life, calculated with respect to the target date of delivery.

C. Measurement Procedure

The agreement of the Ethical Commission regarding the entire measurement procedure was secured in advance. The parents of the subjects also gave their informed consent prior to starting the measurements. Furthermore, the measurements were stopped at any point at the request of the parents. The measurements took place approximately 1 hour after the last feeding and about 1-2 hours before the next feeding of the infants. This was to assure that the infant would be awake and unagitated as required for general movement assessment [4]. Prior to starting the measurement, the infant's bodily dimensions and weight were registered. The room temperature was set at 29°C. As shown in Figure 2, accelerometers were affixed with skin friendly adhesive strips to the child's extremities in defined orientation. The unclothed infant was then placed supine upon a blanket on the floor. Each child performed spontaneous movements for about 15 minutes which were recorded by the measurement system in segments of about 2.5 minutes. If any sensor dropped off during a measurement the dataset was cut at the point of disturbance before the parameters are calculated.

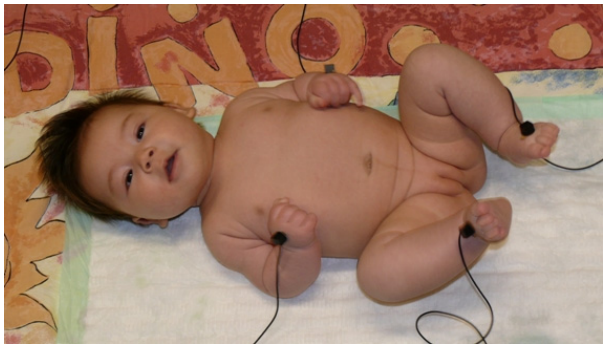

Fig. 2 Example of sensor placement.

D. Parameter extraction

The velocity was computed using the least squares fitting algorithm by The MathWorks (Matlab System Identification Toolbox). The movement trajectory was not calculated because the most of the parameters described by Meinecke depend on acceleration and velocity, as described in the introduction section. Additionally, due to noise effects, the calculation of the trajectory out of acceleration is very imprecise and unstable. So, with the extracted acceleration and velocity data of each sensor it is possible to calculate 32 parameters of the 53 described in [6]. A schedule of the used parameters can be found in the result section. The calculation is exactly equivalent to those used by [6].

E. Optimization of the parameter combination

To identify the optimal parameter combination to separate the best between the affected and healthy group and to contain the expenditure of time a dedicated algorithm had to be used. The optimization method has to search not only the best parameter combination but also the best size of the combination. A convenient solution is a genetic algorithm. Hence the genetic algorithm operates parallel with several possible solutions it is well faster than the complete search done by [6] with comparable reliable results. Furthermore, the genetic algorithm preserves the meaning of the parameters, so that the link to the physiological meanings as described in [6] persists. By dint of this method optimal combinations of parameters and optimal sizes of the combinations were found for each measurement date. Both, size of combination and parameters vary between the three measurement points as also expected by Prechtl and colleagues [4].

F. Classification

After finding the optimal parameter combination for each measurement date a classification system to evaluate the qualification of the parameter combination to distinguish between “healthy” and “at-risk” infants is necessary. To achieve good and comprehensible results as well as preferably low computing time, a decision tree was chosen. Additionally, the possibility of knowledge extraction is the key benefit of decision trees against other classification systems and especially useful in medical applications. In this application the tree uses the extracted parameters to minimize from node to node the impurity, i.e. to separate more and more between healthy and affected children. To evaluate the extracted parameter combinations and the classification measurement data was allocated in an evaluation database and a training database.

III. Results

The preliminary results described below comprise the measurements of newborn babies within their first five month of life. Compared to [6] in this study visibility of the sensors is not a problem, but accelerometers are only fixed on extremities, the calculated parameters contain characteristics only of the hands and feet. The detection rates achievable by the use of chosen parameter combination are predicated on so far unclassified data. Table 1 shows sensitivity (correct classification of affected participants), specificity (correct classification of healthy participants) as well as overall detection rate for all measurement dates reached with the evaluation database.

Table 1 Classification results

Measurement	1st	2nd	3rd
Sensitivity	100%	100%	100%
Specificity	83%	86%	89%
Overall detection rate	89%	88%	92%

IV. Discussion

Particularly with regard to the disadvantages of optical motion analysis systems as high expense, measurements are confined to a restricted volume, and the optical line of sight to the markers can easily be obscured [6], this study shows it is possible to obtain valid kinematic values for quantifying spontaneous motor activity in newborns using accelerometers. As the results published by Meinecke et al. [6] are limited to the movements of the feet due to the measurement system used and were determined only for the first measurement date the extracted parameter combinations are not comparable in respect of content. However, regarding the classification results Table 2 compares the results from Meinecke et al. with the results of this study at the first measurement date.

Table 2 Classification results at the first measurement date from Meinecke et al [6] vs. this study

Measurement	Meinecke et al.	This study
Sensitivity	100%	100 %
Specificity	70%	83 %
Overall detection rate	73%	89 %

Aside from the equal high sensitivity the classification system in this inquiry delivers better results. This was already expected by Meinecke as the consideration of the hand movements provides important information for the separation of healthy and affected infants [4]. Basing on these values comparable classification results can be

achieved as in optical motion analysis systems, but with less expense, and without volume and line-of-sight restrictions. The differences in between spontaneous movements of healthy and ICP-affected infants are highest during the third to fifth months, which correspond to fidgety movements and the absence of fidgety movements [4]. This tendency can be observed in the determined sensitivities and specificity (Table 1) as well. It becomes increasingly easier to classify children from the first to the third measurement date. The minor decrease in the overall detection rate from the first to second measurement date is due to the fuzzy age dependency of the spontaneous motor activity described by Prechtl and colleagues. Due to weak phase transitions between the developmental steps this age group is the inhomogeneous one. Apart from this, a high sensitivity is regarded to be the more important parameter as the non-detection of affected children would have a much worse consequence than an incorrect prediction for a healthy infant.

V. Conclusions

In combination with the low costs, reduced screening time, manageability, portability and the light weight of the measuring device the method presented is able to analyse the movements of newborns using accelerometry for the early detection of movement disorders due to infantile cerebral palsy. Overall detection rates of 89%, 88% and 92% for new patients were achieved. Essentially, this is a better result than that which most physicians, who are not specially trained in evaluating spontaneous motor activity, would be able to reach during visual examination and it is quite comparable to the results of trained physicians [5]. Since the method presented is objective, quantitative and easy to apply, it is suitable for helping to support early diagnosis and quantify therapy success in the daily routine of pediatric clinics. Moreover, the measurement system developed is an important step towards an easy to use, payable, computer-based movement analysis system for newborns with and without ICP. These are essential requirements in order to make this system available for the screening of large numbers of infants. With an early diagnosis of ICP it is possible to minimize follow-up problems and thus to relieve the health care system and above all to significantly improve the quality of life for both the patients and their families.

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Author: Franziska Heinze
Institute: Chair of Applied Medical Engineering, RWTH Aachen University, Germany
Street: Pauwelsstrasse 20
City: 52074 Aachen
Country: Germany
Email: heinze@hia.rwth-aachen.de