33rd Annual International Conference of the IEEE EMBS
Boston, Massachusetts USA, August 30 - September 3, 2011

Instrumented toys for studying power and precision grasp forces in infants

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Abstract —**Currently the study of infants grasping development is purely clinical, based on functional scales or on the observation of the infant while playing; no quantitative variables are measured or known for diagnosis of eventually disturbed development. The aim of this work is to show the results of a longitudinal study achieved by using a "baby gym" composed by a set of instrumented toys, as a tool to measure and stimulate grasping actions, in infants from 4 to 9 months of life. The study has been carried out with 7 healthy infants and it was observed, during infants development, an increase of precision grasp and a reduction of power grasp with age. Moreover the forces applied for performing both precision and power grasp increase with age. The proposed devices represent a valid tool for continuous and quantitative measuring infants manual function and motor development, without being distressful for the infant and consequently it could be suitable for early intervention training during the first year of life. The same system, in fact, could be used with infants at high risk for developmental motor disorder in order to evaluate any potential difference from control healthy infants.**

I. Introduction

THE young human brain is highly plastic, thus brain lesions occurring during development interfere with the innate development of the architecture, connectivity, and mapping of functions and trigger modifications in structure, wiring, and representations. In childhood, the motor cortex and/or the corticospinal tract is a common site of brain damage and the prenatal or immediately perinatal period is the most common time for brain damage to occur. It is now increasingly appreciated that the corticospinal system, after early injury, is capable of substantial reorganisation and such reorganisation is likely to underlie the partial recovery of function. The processes of plasticity, in healthy and damaged brain, are widespread prenatally, but continue postnatally, and to a lesser extent, into adulthood. Functional and anatomical evidence demonstrates that neural plasticity can be potentiated and shaped by activity and the impact of experiences on neural and behavioral development is influenced by the timing, duration, and intensity of stimuli [1].

These factors coupled with the decreasing trend of plasticity across development, underscore the points outlined above concerning the urgency of starting prevention and intervention programs as soon as possible in infants with developmental disorders risks.

The essential nature of rehabilitation in the first year of life is the early intervention which means: intervening as soon as possible to tackle problems that have already emerged due to prenatal or congenital brain disorders [2]. It challenges the traditional adult-like medical model of neuro-rehabilitation that acts on an evident damaged function. On the contrary, early intervention is carried out in a critical period of development (i.e. a time window during which a specific function develops very rapidly) whereas initial signs of atypical development are present but before they become overt.

The target of early intervention training is therefore to strengthen the capacity of the brain to compensate for brain lesion induced deficits and allow a relatively "normal" organised behavior and a better functional outcome both of motor and cognitive development. At the core of a modern rehabilitation approach is the understanding that awareness, cognition and movement are really inseparable, and that the development or recovery of ability in any of these domains requires the integrated engagement of the impaired individuals and their brain in all of these dimensions of improvement [3].

In summary, the development of action and perception, and the development of the nervous system and growth of the body mutually influence each other in the process of forming increasingly sophisticated means of solving action problems. One important action system that develops in the first year of life is grasping and it can represent the target system of early intervention with a package based on action perception model of motor and cognitive development [4]. Moreover, visual function undergoes a rapid maturation in the first year of life [5] and behavioral and electrophysiological tools can be used to assess visual development in young infants.

Based on the previous considerations, we proposed a mechatronic platform [6] as a tool to measure and stimulate infants movement during the acts of reaching and grasping, primarily to define new standards on early intervention in infants. The proposed platform is a "baby gym" composed by a set of instrumented toys equipped with a variety of sensors designed for the assessment/stimulation of upper limb of infants between 4 and 9 months of life [6]-[9]. This innovative setting is based on the concept of ecological

Manuscript received June 20, 2011.
This work was partially supported by Tuscany Region, by Fondation Motrice Grant to FC and by STMicroelectronics S.r.l. Grant to SMS.
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environment; the infant should not perceive the presence of instrumentations at all, or like to play with them (e.g. instrumented toys) [10].

In particular, the main goals of this study are to evaluate the development of the force exerted by healthy infants from 4 to 9 months of life on sensorized toys and to understand the changes on the type of play due to the development of manipulation capabilities. In our experimental setting the tested variables (i.e. the size of the objects, its distance from infant's eyes,) and the range of age of the tested infants (all typically developing) do not support an influence of visual maturation on our results thus leading to not include such a measurement in the study.

In this paper we present the results of a longitudinal study carried out by using the baby gym with 7 healthy infants.

II. Materials and Methods

A. The Mechatronic Gym

A mechatronic gym has been purposively developed by integrating sensors and visual and auditory stimulations to the gym structure and hanging toys for monitoring, measuring and stimulating the infants actions on the gym devices, but operating in an ecological environment and without being distressful to the infant.

The gym mechanical structure has been developed in order to reconfigure it (height, width and structure opening angle) according to different infants' anthropometrics [11].

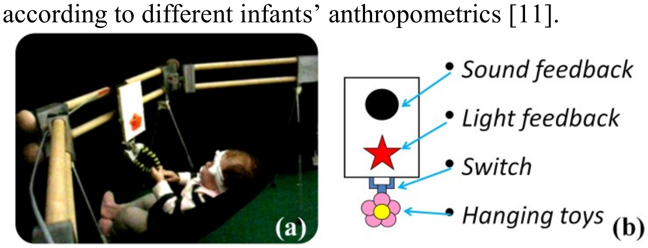

Fig. 1. a) mechanical structure and b) functional block.

In Fig. 1a the mechanical structure of the gym is shown during clinical trials where infant was placed in a sitting position on the basis of their postural control (age dependent). A functional block (see Fig. 1b) has been created including auditory (isolated sounds or melodies) and visual (alternating coloured lights) stimulations which can be partially controlled by the operator and partially evoked by infants endogenous motor behavior, to stimulate the infants and give a reward. The functional block can be moved horizontally along the structure for performing different tasks (central or lateral task).

B. Sensorized Toys

The sensorized devices were soft toys, like puppets, derived from commercial toys. The approach adopted in this study to induce an effective grasping in a "spontaneous" way, without requiring an aware collaboration by the subject, was based on the concept of affordance [12], i.e. the property of objects to encourage and suggests the use to be done with them, given by their shape. In our case the affordance can, in part, guide the infant to perform certain movements instead of others [13].

On the basis of the clinical specifications, the hanging toys were equipped with two kinds of sensors:

1) an uncompensated pressure transducer measuring pressure applied by infants grasping actions in the range of 0-35 kPa. It is based on four active element piezoresistive bridge construction in a gauge style, atmospheric pressure is used as a reference;

2) a flexible Force Sensing Resistors (FSR®, [14]) sensor able to measure the force applied in the normal direction to its surface in the range of 0-20 N.

Small size, light weight, robustness, safety [15], low cost and type of grasping (precision or power) were among the key features taken into account during the technical design of three different sensorized toys:

- Cow toy [6]: was 100×40 mm, whereas cow arms were 25×25 mm (see Fig. 2a) and perfectly fit with infants' hand dimension constraints [1]. The main body of the cow allowed to measure the infants power grasps (large diameter) by means of the pressure sensor, whereas the cow arms that encourage precision grasp were equipped with FSR®;
- Flower toy [6]: was 85×85 mm, in particular each petal was 25×20 mm (see Fig. 2b), containing an FSR® for measuring precision grasp;
- Ring toy [8]: the total diameter was 93 mm, whereas considering the section, the diameter was 15 mm (Fig. 2c); the toy was equipped with a pressure sensor that allowed to measure the infants' power grasps (small diameter).

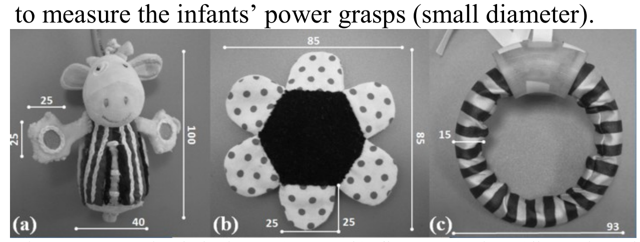

Fig. 2. Sensorized devices: a) cow, b) flower, c) ring (dimensions in mm).

Whereas FSR® could be directly embedded inside the toys, each pressure sensor had to be connected to a silicone air chamber in order to measure internal pressure variations caused by the pressure exerted by the infants (a linear proportionality).

All the toys had an attractive aesthetic by the use of contrasting colours.

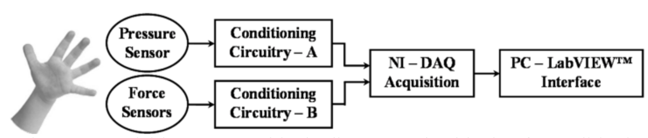

Fig. 3. Acquisition system block diagram. The block of Conditioning Circuitry is different for pressure (A) and force (B) sensors.

A purposive acquisition system (see Fig. 3) has been designed in order to acquire the signal coming from the devices and collect the data. Moreover a calibration of each sensorized toy has been carried out to convert the electrical signal to the equivalent pressure measurement.

III. Longitudinal Study

A. Protocol

Seven healthy infants (5 males and 2 females), without atypically developing features were recruited as control group for a longitudinal study on infants motor development. The infants were tested from 21 weeks of age until 41 weeks for a total of ten trials.

A parent of each infant signed an informed consent statement. The infants were placed on a seat in front of the gym and played with the toys hanged on the functional block separately. Each toy can be hanged centrally or laterally to the infant, on both sides of the gym structure (see Fig. 1a). The clinical protocol was composed by 3 tasks, for each toy, lasting 120 s for central task or 60 s for lateral ones.

The grasping actions were measured by force and pressure sensors inside the toys and the trials were recorded using a camera placed behind of the infant.

B. Data Analysis

Two different types of data analysis have been performed; a first qualitative analysis based on the evaluation of the grasping actions from a video processing and a quantitative one based on the force and pressure signals measured by the toys sensors. The data reported refers to the sensorized cow toy.

In the first type of data analysis the trend of the percentage of power and precision grasping actions has been studied to assess the changes across different weeks of age: a linear regression study has been realized to demonstrate the trend of the data; a linear model has been used to model the data and to evaluate the reliability of parameters, the significance level of R^2 value ($p<0.05$) was calculated and reported.

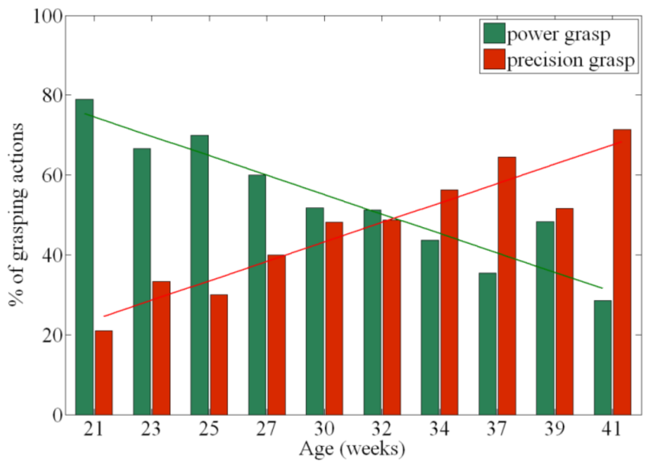

Fig. 4. Percentage of power and precision grasping actions at different weeks of age.

In the second quantitative study, pressure and force sensors data were extracted for each infant, for each week, identifying the hand used through a video analysis thus isolating signals generated by the selected grasps related to the two different hands (expressed in Pascal and Newton) [8]. The numeric string were analyzed by calculating their mean value and the standard deviation considering the selected data as single and separated observation composing the whole groups of healthy data collected for each week, task and hand action.

In order to evaluate a trend of data during infants development, independent samples t-test has been chosen to detect significant differences in terms of grasping actions values (only right and left hand) selecting the following weeks of age of the infants among the ten tests acquired: the first (21st wk), the mid-time (32nd wk) and the last (41st wk) one of longitudinal study.

IV. Results

A. Longitudinal study of the evolution of power and precision grasp

In the study we considered the central task data and results showed that there was a significant increase in precision grasping actions (performed on the cow arms), ($r=+0.94$, $p<0.0001$) and a significant reduction ($r=-0.94$, $p<0.0001$) of power grasp on cow body with ages (Fig. 4).

B. Longitudinal study and focus on the trend of data

The following figures show the boxplots of the t-test results for the cow body (pressure signal, Fig. 5) and cow arms (force signals, Fig. 6), while Table I and Table II report report the relative ranges and p values .

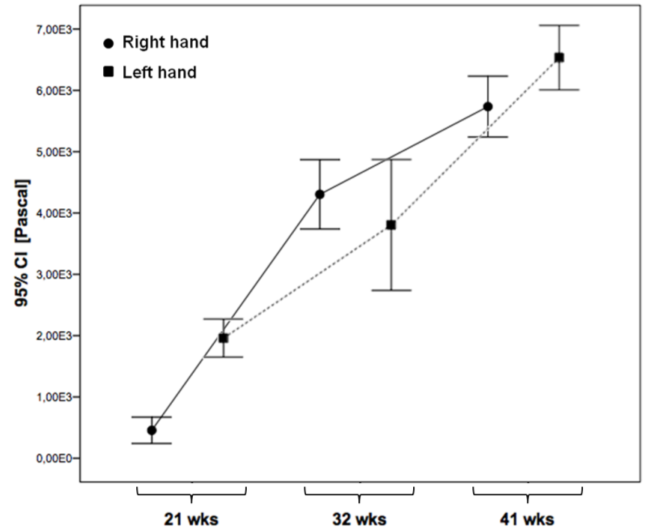

Fig. 5. Boxplot of pressure data: mean and 95% Confidence Interval of the right hand (●) and left hand (■) at different weeks.

TABLE I
Pressure Ranges and p Value Among Different Weeks

Weeks	Hand	Range [Pascal]	p value
21-32	Right	459.5 - 4308.3	<0.005
	Left	1928.0 - 3769.8	<0.0005
32-41	Right	4308.3 - 5739.6	<0.001
	Left	3769.8 - 6482.5	<0.0005
21-41	Right	459.5 - 5739.6	<0.000001
	Left	1928.0 - 6482.5	<0.000001

The trends indicate a significant increase in this variable between the first week and the mid-time (21-32), between the mid-time and the last week (32-41) and also between the first and the last week (21-41). The same trend was observable in force data coming from the FSR® sensors in the cow arms.

These trends show that at the onset of reaching with successful grasping, the infants perform more the power grasp than the precision one. Moreover, the precision grasp that is a form of mature grasp and a sign of typical development increases significantly across the first year of life. Both power and precision grasp forces increased significantly among all ages examined.

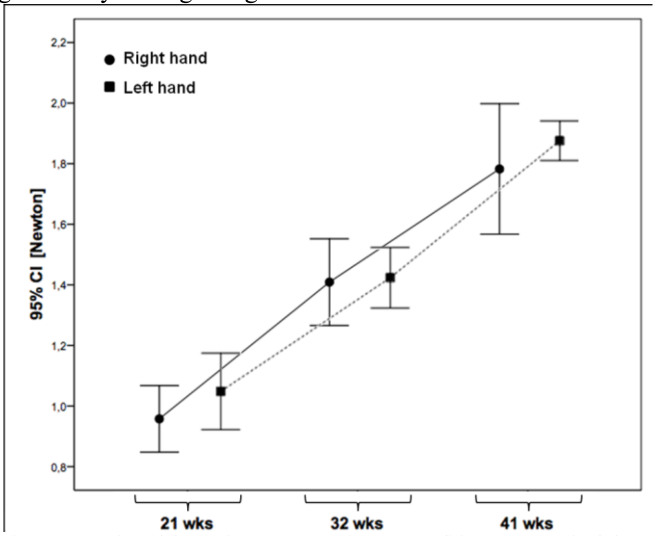

Fig. 6. Boxplot of force data: mean and 95% Confidence Interval of the right hand (●) and left hand (■) at different weeks.

TABLE II
FORCE RANGES AND P VALUE AMONG DIFFERENT WEEKS

Weeks	Hand	Range [Newton]	p value
21-32	Right	0.96 -1.41	<0.0001
	Left	1.06 - 1.44	<0.000001
32-41	Right	1.41 - 1.78	<0.005
	Left	1.44 - 1.89	<0.000001
21-41	Right	0.96 - 1.78	<0.000001
	Left	1.06 - 1.89	<0.000001

Differences in terms of power grasp have been noticed when analyzing signals coming from sensors on cow body and on the ring. The toys have different dimensions and consequently the infants performed a power grasp (small diameter) on the ring toy and a power grasp (large diameter) on the cow toy. In terms of force development, whereas the infants at 32 weeks are able to produce their maximum force with small diameter power grasp in the ring, the large diameter power grasp increased only after 32 weeks. At the same time, the precision grasp increass between all ages examined [16].

V. CONCLUSION

This paper shows clinical results about the use of an instrumented toy for monitoring infants grasping development. These results are in accordance with those obtained with the another sensorized toy, the ring shaped one, already presented by the authors [9]. They show an increase of precision grasp and a reduction of power grasp with age, and an increase with the age, as well, of the forces applied for performing both precision and power. Moreover during these longitudinal trials infants have shown a good grade of involvement and acceptance of the baby gym thus demonstrating the distressfulness of the system. The proposed sensorized toys allowed to monitor and to quantitative measure infants manual function and motor development while operating in an ecological environment. The entire mechatronic system could be used with infants at high risk for developmental motor disorders in order to evaluate any potential difference from control healthy infants. In particular, our setting, inspired to commercial baby gym for infants, reproduces home-like situations, specially suitable for a customized and ecological training during the first year of life.

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