A Technological Approach to Studying Motor Planning Ability in Children at High Risk for ASD *

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***Abstract*— In this work we propose a new method to study the development of motor planning abilities in children and, in particular, in children at high risk for ASD. Although several modified motor signs have been found in children with ASD, no specific markers enabling the early assessment of risk have been found yet. In this work, we discuss the problem posed by objective and quantitative behavioral analysis in non-structured environment. After an initial description of the main constraints imposed by the ecological approach, a technological and methodological solution to these issues is presented. Preliminary results on 12 children are reported and briefly discussed.**

I. Introduction

Several studies show that children with Autism Spectrum Disorder (ASD) exhibit deficits in postural reflexes [1]-[3], repetitive and stereotyped movements, awkward patterns of object manipulation, lack of purposeful exploratory movements [2], gaze abnormalities [4], unusual gait pattern [5], and alterations of movement planning and execution [6][7], which express themselves as "hyper-dexterity" [8], [9]. These observations are consistent with a large body of evidence of subtle structural and functional abnormalities of cortical and subcortical neural systems involved in movement planning and execution, such as the prefrontal cortex, the basal ganglia and the cerebellum (see [10], for a review).

Difficulties in movement planning may affect development well beyond the motor domain. In particular, studies of movement planning in reaching-grasping-placing sequence of movements when the final goal of the sequence require different level of precision (i.e. [6], [7])report significant differences in the reaching phase between ASD and Typically Developing (TD) children, suggesting that TD children plan the movement during reaching phase. While these difficulties have been studied in children already diagnosed with ASD, little work [11], [12] has addressed this topic in infants before the diagnosis and during development to assess how this competence develops. The reason is threefold: on one hand, infants and very young children are not cooperative participants, and the protocols used in the reported previous studies are not suited for them (methodological issue); on the other hand a suited technology is necessary to study these subjects in non-structured environments (technological issue); finally, such a study requires a very large sample to have enough participants with a later diagnosis of ASD, since its prevalence is very low in the general population.

The effect of the last problem may be reduced by enrolling in the study infants who have an older sibling already diagnosed with ASD: they are approximately 200 times more likely (High Risk subjects, HR) [13] to receive an ASD diagnosis than those in the general population (Low Risk subjects, LR).

In this work, we address the first two issues proposing a technological solution to study the development of motor planning ability in children, presenting the protocol used to study this skill and discussing the methodology adopted to face the problem introduced by the non-structured environment and the non-cooperative subjects. Finally, results on 12 subjects (6 HR and 6 LR) at 24 and 36 months of age are presented and discussed.

II. MATERIALS AND METHODS

A. *Materials*

The study of motor skill development during first years of life requires a long time of observation and, to be effective, it should not be distressful or requires obtrusive tools. To date there are no technological tools to go beyond a qualitative analysis of early motor signs, that enable quantitative and objective (rather independent) assessment of young children in non-structured environments. Usually, studies are performed with high-cost and sophisticated systems like gaze tracking device, stereophotogrammetric movement analysis systems, and force platforms in very structured laboratory environments. Screening a large number of children for diagnostic purposes is not feasible with these systems due to the high costs, limited availability, and poor transportability of the equipment.

To overcome this issue, orientation tracking and kinematic measurement based on inertial and magnetic sensors represents a promising solution. Indeed, accelerometers to sense acceleration and gravity, magnetometers for use as compass and gyroscopes for measuring angular velocity rely solely upon gravitational field and geomagnetic fields, ubiquitously present on Earth and require no additional field sources, i.e. sourceless. For this reason, we have developed and successfully used a wireless magneto-inertial sensor to study motor development [14], fine manipulation [15] [16], and gesture production [17]

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in infants and children. For a detailed description of the sensor please refer to [18]. The overall architecture of the sensing device is reported in Fig. 1: it allow to sense ± 2 g accelerations, ± 1200 deg/sec angular rates, and ± 1 Gauss and to reconstruct the orientation with an angular error lower than 2 deg [18].

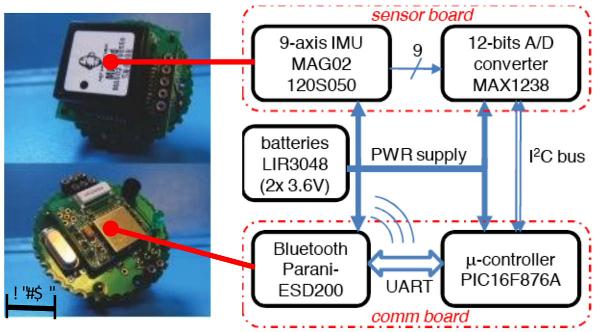

Fig. 1 Electronic sensing core and its Architecture

This work is focused on the study of kinematic of young children movements during simple goal-directed reaching. For this reason, we used a set of two magneto-inertial sensors based on the same sensor embedded in the wireless sensing core previously developed, but in a wired configuration. We made this choice to avoid the placement of the batteries on the child's arm to reduce the overall weight of the sensors, which can modify the reaching movement. A I2C bus has been used to guarantee the synchronization from the two sensors.

B. Methods

In this study we used a motor task that involves the fine-grained object manipulation: *The Tower Building Task* [19]. This protocol involves two conditions in which the action goal is modified, thereby varying the precision demand of the task. In the first condition, called *Throw,* children are asked to reach for and place a small cube (block) into a large open container; in the second condition, called *Stack*, children have to reach for and place four identical blocks, one at a time, on a target block to make a tower. The *Throw* condition requires less precision performance than the *Stack* condition. Moreover, in the *Stack* condition, the precision demand increases with the number of piled-up blocks. Varying precision requirements should affect the kinematics of movement and the temporal organization of reaching (i.e. reaching movement time vs. placement movement time). In this study we used 5 blocks (side block 5.3 cm) and a container of 18 cm x 12 cm x 7 cm. Each session was video-recorded and videos were segmented by trained coders to identify the reaching and placement movements. *Reaching* starts when the hand began the approach toward the object and ends when the hand reached the object. *Placement* begins as the object is lifted up and ends when it is released.

The experimental sessions were carried out at home or at the child's daycare center, and began after an initial familiarization period. During this period, the experimenters played with the child and asked him/her to wear the magneto-inertial sensor (two colored bracelets placed on the wrists). After this phase the experiment began. At the beginning of each condition, the experimenter demonstrated the task to the child, while he/she is seated in front of a table on which the stimuli were placed (see Fig. 2). Children were encouraged to perform each reach starting with hands from the same location, putting their hands on two animal stickers placed on table.

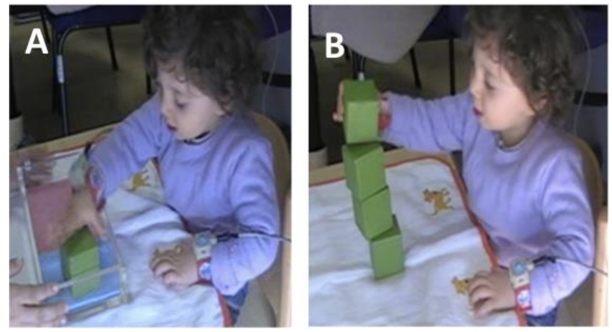

Fig. 2 A) Throw Condition; B) Stack Condition

The kinematics of each segmented movement was objectively assessed by means of the two wired bracelets since we did not force the child to perform the movement with a specific arm. Only data from the arm effectively used by the child were considered for the analysis. In particular, we measured the linear acceleration, i.e. the acceleration due to the movement only without gravitational field, and calculated the mean and the peak of its absolute value (respectively MRA, i.e. Mean Reaching linear Acceleration see [14] for details, and PRA, i.e. Peak Reaching Acceleration). Finally, we calculate the smoothness of movement as mean squared Jerk according to [20] as:

$$J = \frac{1}{t_2 - t_1} \int_{t1}^{t2} \dot{a}(t)dt$$

Higher values of this index reflect more correction and on line changes during movement. In a uniform accelerated movement it should be equal to zero. In addition, reaching, grasping, and placement times (respectively RT, GT, PT) were also measured from video recording. We utilized this solution to avoid the use of cumbersome equipment like a structured board as [21], which requires additional time and space for setup. This experimental design is subjected to several uncontrolled variables, which should affect the final results of the experiment. To correct for slight variations in the relative positions of the child and the blocks in the naturalistic setting, we computed a set of relative indices. In particular we define the Percentage Duration of Reaching (PDR) as:

$$PDR = \frac{RT}{RT + GT + PT}$$

and the Percentage Acceleration of Reaching (PAR) as:

$$PAR = \frac{MRA}{PRA}$$

Finally, we verified the inter-rater reliability between coders. Specifically, reliability was assessed for detection of reaching and placement onset and offset for each trial. The maximum difference value accepted was 0.09 s. The agreement between coders for reach onset time was 94%, for reach offset and place onset time was 100%, and for place offset 88%.

allow verification of these preliminary results and the suitability of the proposed methodology. Future developments will investigate an automatic process for data segmentation.

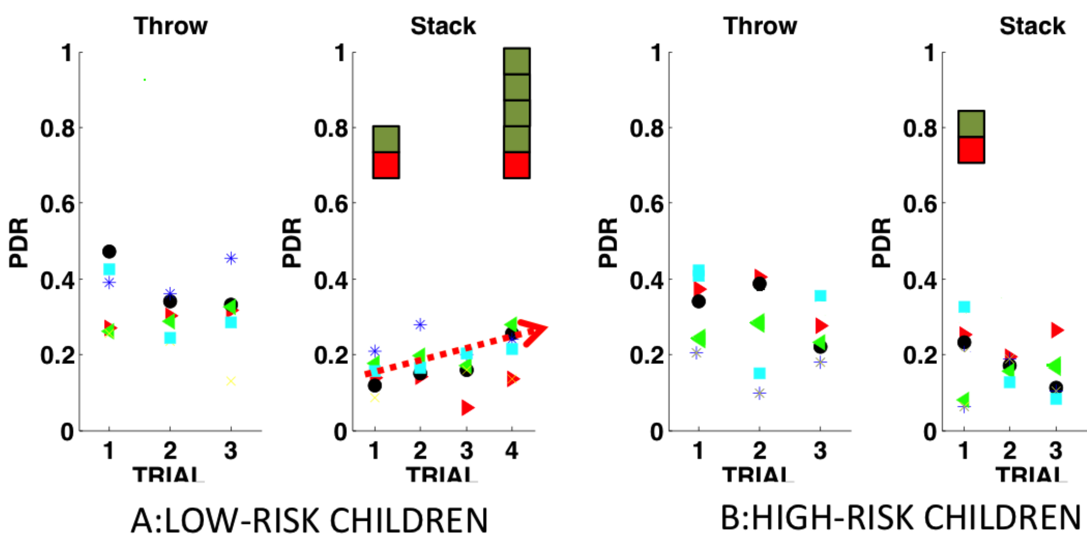

Fig. 3 Percentage Duration of Reaching: A) LR children; B) HR children. In the Stack condition children have to pile up 4 cubes on a target block, in red. During each trial they add a block.

III. RESULTS

We enrolled 12 children at 24 and 36 months of age to test the proposed approach: 6 were HR and 6were LR. A total of 84 trials were presented. All trials in which children changed hands between reaching and placement were excluded from analysis. A total of 10 trials were excluded for this reason, plus an additional 2 trials due to equipment failure.

Given the relatively small sample size and number of trials, we did not examine age effects and focused instead on the effect of risk status. According to the findings reported in literature, LR children should increase their reaching times as the demand for greater precision increases across trials in the *Stack* condition. A preliminary data analysis did not indicate any effect of trial on PDR in the *Throw* condition (see Fig. 3) for LR children, but there was an increase across trials in the *Stack* condition. A one-way ANOVA confirmed this observation, revealing a nearly significant increase in PDR between trials 1 and 4 only in the Stack condition for LR children ($F(1,10)=4.1$, $p=0.07$). No similar pattern was observed for HR subjects. No significant increases were observed for PAR (see Fig. 4) or Jerk.

IV. CONCLUSION

In this work an innovative technological approach to the study of motor control in unstructured environments has been presented. Limitations due to the ecological constraints have been discussed and technological and methodological solutions presented. A preliminary study of 12 children revealed some positive findings. A larger sample size will

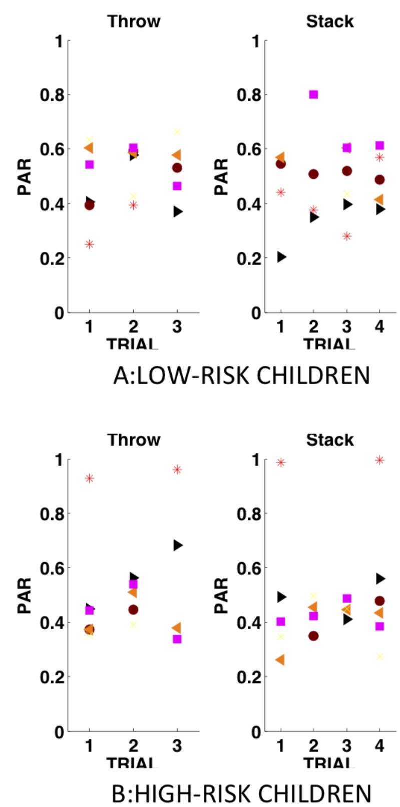

Fig. 4 Percentage acceleration of reaching

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