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Cognitive procedural learning among children and adolescents with or without spastic cerebral palsy: The differential effect of age

M. Gofer-Levi [a], T. Silberg [a,b,*], A. Brezner [b], E. Vakil [a]

[a] The Department of Psychology, Bar Ilan University, Ramat-Gan 52900, Israel
[b] The Edmond and Lily Safra Children's Hospital, Chaim Sheba Medical Center, Tel-Hashomer 52621, Israel

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ABSTRACT

Introduction: Children learn to engage their surroundings skillfully, adopting implicit knowledge of complex regularities and associations. Probabilistic classification learning (PCL) is a type of cognitive procedural learning in which different cues are probabilistically associated with specific outcomes. Little is known about the effects of developmental disorders on cognitive skill acquisition.
Methods: Twenty-four children and adolescents with cerebral palsy (CP) were compared to 24 typically developing (TD) youth in their ability to learn probabilistic associations. Performance was examined in relation to general cognitive abilities, level of motor impairment and age.
Results: Improvement in PCL was observed for all participants, with no relation to IQ. An age effect was found only among TD children.
Conclusions: Learning curves of children with CP on a cognitive procedural learning task differ from those of TD peers and do not appear to be age sensitive.

1. Introduction

Children develop and grow in stimuli-rich environments. Interestingly, their growing abilities reflect adaptation to regularities in the environment, which evolve without an explicit intention to learn (Perruchet & Pacton, 2006). This form of learning, which occurs without clear awareness of what is learned and is expressed through improved performance, was termed by Reber "Implicit learning" (Reber, 1967).

Implicit learning includes several sub-systems in which learning is expressed through performance, rather than through intentional recall. Such sub-systems include procedural/skill learning, classical conditioning, and priming (Graf & Schacter, 1985). Specifically, procedural learning refers to the ability to acquire and perform rule-based information, as a result of repeated exposure and practice. Acquisition of the skill is indicated via improvement in performance (Cohen & Squire, 1980; Squire, 2004).

Numerous studies on the ability to learn implicitly have demonstrated the use of a variety of procedural learning tasks. These tasks can be categorized according to the basic principal faculties required for the performance on each task.

* Corresponding author at: The Department of Psychology, Bar Ilan University, Ramat-Gan 52900, Israel. Tel.: +972 35305038; fax: +972 35302045; mobile: +972 507693933.
E-mail addresses: mgoferlevi@gmail.com (M. Gofer-Levi), tamarsilberg@gmail.com (T. Silberg), amichai.brezner@sheba.health.gov.il (A. Brezner), eli.vakil@biu.ac.il (E. Vakil).

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Table 1
Frequently used procedural learning tasks categorized according to three basic task requirements:.

Task	Perceptual	Conceptual	Motor
Tower of Hanoi[a]/Tower of London[b]		✓	✓
Artificial Grammar[c]		✓	
Probabilistic classification learning[d]		✓	
Mirror Drawing[e]	✓		✓
Serial Reaction Time[f]	✓		✓
Porteus Mazes[g]	✓		✓
Mirror reading[h]	✓	✓	

Note: Tasks were categorized according to the basic principal faculties required for the performance on each task.
[a] Grafman et al. (1992).
[b] Asato, Sweeney, and Luna (2006).
[c] Perruchet, Vinter, Pacteau, and Gallego (2002).
[d] Gluck, Shohamy, and Myers (2002).
[e] Edelstein et al. (2004).
[f] Deroost & Soetens (2006).
[g] Vakil, Blachstein, and Soroker (2004).
[h] Koenig, Thomas-Anterion, and Laurent (1999).

Table 1 depicts a short typology of the most frequently used tasks according to three principal faculties. The first faculty is perceptual (i.e., visual) ability. For example: mirror reading, where one is required to trace a given path by looking at the reflection of the pattern in a mirror (Ackerman & Cianciolo, 2000). The second faculty is cognitive (or conceptual), requiring problem solving. For example: the Tower of Hanoi task (TOH) (Grafman et al., 1992), where one is required to reach a goal position of a set of colored rings with a minimal number of moves (Vakil & Hoffman, 2004). The third refers to the requirement for motor maneuvers. For example the Serial Reaction Time (SRT) task, in which learning is acquired via the performance of repeated sets of sequences of finger movements (Deroost & Soetens, 2006; Nissen & Bullemer, 1987).

In a previous study (Gofer-Levi, Silberg, Brezner, & Vakil, 2013) we reported on the performance of a specific SRT task by children with cerebral palsy (CP) compared to typically developing (TD) children. The SRT task enabled distinguishing between the explicit and implicit component of motor procedural learning (Robertson, 2007). We demonstrated that children with CP were able to acquire the skill, when provided with explicit verbal instructions, but were unable to learn the specific repeated sequence, proving to have a deficit in motor implicit learning. Given the deficit in the implicit aspect of motor procedural learning, we opt to examine pure, non-motor, cognitive aspects of procedural learning among children and adolescents with CP in the current study. In this manner, the current study will promote a more comprehensive picture of procedural learning among children with CP.

Out of the four possible cognitive procedural learning tasks presented in Table 1 (all demonstrating an implicit learning component), the probabilistic classification learning (PCL) task was chosen. This task was selected since the required performance on one of the alternatives, TOH, artificial grammar, or mirror reading task, could possibly be too difficult for these children, secondary to their motor impairment or as a result of the literacy impairment commonly reported among this population (Dahlgren-Sandberg, 2006; Novak, Hines, Goldsmith, & Barclay, 2012). In addition there is relatively no time limitation in the PCL task, a demand which often feeds back on the cognitive performance of children with CP (Bottcher, Flachs, & Uldall, 2010).

PCL circumvents the use of declarative learning and memory by probabilistically associating cues with specific outcomes. This probabilistic nature leads participants to believe they are simply guessing the outcomes, thus preserving the implicit aspect in their procedural learning. With repeated exposures, implicit learning of the cue-outcome associations is demonstrated via an increase in the percentage of optimal responses from one block of presentations to another (Marsh, Alexander, Packard, Zhu, & Peterson, 2005; Marsh et al., 2004).

Cognitive procedural learning tasks have been reported to be sensitive to developmental stages (Wasserman, 2003). For example, Spitz, Minsky, and Bessellieu (1985) reported two periods of significant improvement in the ability to solve the TOH task: the first around the age of 8 and the second around the age of 12. In a similar manner, Ahonniska, Ahonen, Aro, Tolvanen, and Lyytinen (2000) examined repeated assessments of the TOH task and reported on age dependent performance. They divided their participants into two age groups (i.e., young = 7–8 years, and old = 11–12) and showed that the older participants reached a higher level of performance, and their learning rate was steeper than that of the younger group. To our knowledge, no study has yet examined the effect of age on performance on the PCL task.

Few studies have examined performance on the PCL task in children with neurodevelopmental disorders. For example, a study with participants diagnosed with Gilles de la Tourette syndrome, a neurodevelopmental disorder characterized by motor and vocal tics, reported that participants showed impaired performance on a PCL task. The authors indicated that participants' performance on the PCL task was significantly lower than controls, regardless of their age. This finding suggests that impairments in this type of learning do not simply reflect the presence of an immature cognitive processing skill that improves later in life (Marsh et al., 2005, 2004), but, rather they may indicate a more stable deficit in this specific syndrome. In addition, Mayor-Dubois, Maeder, Zesiger, and Roulet-Perez (2010) have reported that children with basal ganglia pathology of various etiologies were impaired on the PCL task. These children demonstrated an inability to learn cue-outcome associations in the first 100 trials, though they did eventually reach the same level as the controls by the end of the task.

CP is an umbrella term that describes a group of heterogeneous disorders of movement and posture in terms of etiology and severity, attributed to non-progressive brain disturbances that occurred in the developing brain. The motor disorders are often accompanied by disorders of sensation, cognition, perception, and behavior (Rosenbaum et al., 2007). The severity of CP is classified according to the child's ambulatory performance as measured by the Gross Motor Function Classification System (GMFCS) (Palisano et al., 1997). Another, older, classification relates to the type of variability in motor tone that is typical for the child's movement impairment, like spasticity, dyskinesia, etc.

While the motor impairment tends to receive most of the research and clinical attention, for many children it is the accompanying problems, rather than the motor limitation, which often leaves them at a disabling position compared with their peers (Pellegrino, 2002). Furthermore, it has been recently reported that about 50% of children with CP demonstrate at least one specific learning difficulty (Novak et al., 2012). Thus, there is ample probability for a deficit in cognitive procedural learning in this population. Yet, to our knowledge, no study has specifically addressed the issue of cognitive procedural learning among children and adolescents with CP. Furthermore, while several studies have recently reported on sequential learning among children with CP, their conclusions regarding procedural learning should be considered with caution, since they did not address the implicit learning component underlying their performance. This differentiation is important for understanding the cognitive processes underlying procedural learning and can be achieved by using a more sensitive task, such as the PCL task.

However, the exact nature of the relationship between measures of general cognitive ability (e.g., IQ) and the ability to acquire procedural skills is not conclusive (Gebauer & Mackintosh, 2007; Maybery, Taylor, & O'Brien-Malone, 1995; but see also Fletcher, Maybery, & Bennett, 2000; Gofer-Levi et al., 2013). Reber (1993), for example, postulated that among TD children, procedural learning should be independent from the level of IQ, based on the assumption that implicit learning is evolutionary older than explicit cognition. On the other hand, Yeates and Enrile (2005) demonstrated that procedural learning was related to age and IQ. In a previous study among children and adolescents with CP we found no support for Reber's suggestion, and demonstrated that performance on an implicit motor sequence learning task was associated with non-verbal intelligence (Gofer-Levi et al., 2013). Hence, we aimed to examine if the relationship between IQ and implicit procedural learning is also valid for a cognitive procedural task such as the PCL.

More specific cognitive abilities that may be related to cognitive procedural learning are the executive functions (EF). EF is an umbrella term for high level cognitive skills necessary for goal directed behavior, working memory, cognitive flexibility, problem solving etc. (Anderson, Anderson, Northam, Jacobs, & Catroppa, 2001; Diamond, 2002; Miller & Cohen, 2001). In the current context we specifically refer to the proficiency for problem solving and cognitive flexibility. An ample number of studies have marked the age of 12 as a period of significant improvements in some aspects of EF, such as working memory, planning, and problem-solving skills, while other aspects reached adult levels of performance only later in adolescence (Anderson et al., 2001; Brocki & Bohlin, 2004; Chelune & Thompson, 1987; Huizinga, Dolan, & van der Molen, 2006; Levin et al., 1991; Welsh, Pennington, & Groisser, 1991). The TOH, mentioned earlier as a cognitive procedural learning task, is also commonly used as a measure of EF, demonstrating age-related performance. For example, Ahonniska and colleagues (2000) reported that older children (11–12 years) outperformed younger children (7–8 years) in the TOH task. It is possible that the development of various aspects of EFs within these years account for the increase in the learning potential of the older children (Passler, Isaac, & Hynd, 1985), enhancing the likelihood that performance on cognitive procedural learning is mediated by EF abilities.

To summarize, the current study aimed at examining the ability of children and adolescents with spastic CP to acquire a specific cognitive skill as an indicator of their ability for procedural learning. Additionally, we wanted to examine if the previously reported age effect among TD children for various cognitive procedural learning tasks would be present in the same manner in children and adolescents with CP when administering the PCL task; and to examine the effect of different child characteristics, such as severity of motor impairment (GMFCS level), IQ and EF, on the ability to acquire a cognitive procedural skill.

We hypothesized that children and adolescents with CP would demonstrate an impaired learning rate compared to controls, as reported in studies with different neurological populations. To our knowledge, no study has specifically addressed the issue of cognitive procedural learning among children and adolescents with CP. Yet, cognitive procedural learning might underpin many cognitive abilities such as academic achievements (i.e., arithmetic, reading), known to be impaired among the CP population (Ahonniska-Assa, Silberg, Levin, Brezner & Levav, 2012; Dahlgren-Sandberg, 2006; Jenks, van Lieshout, & de Moor, 2009). Certainly, understanding the ability to acquire basic cognitive skills in children and adolescents with CP could help professionals compose specific intervention programs relevant to the individual's learning abilities.

2. Methods

2.1. Participants

In the current study we used a case-control design that consisted of a group of children and adolescents with bilateral spastic CP and a group of TD controls. TD controls were compared to participants in the CP group with respect to extraneous

Table 2
Demographic, clinical and neuropsychological information of the participants.

Cerebral palsy								Typically developing			
Child number	Age	Gender	Birth weight (kg)	Gestational age (weeks)	GMFCS	Raven's progressive matrices *Z* score	Category test *Z* score	Age	Gender	Raven's progressive matrices *Z* score	Category test *Z* score
1	17	M	NA	NA	3	−3	−3	17	M	2.3	1.7
2	10	F	NA	NA	4	−3	−0.8	10	F	1	−0.6
3	20	F	1.730	32	3	−3	NA	18	F	2.3	−0.5
4	20	F	1.380	27	3	−3	−2.6	17	F	2.3	−0.8
5	16	M	1.700	31	3	−3	NA	16	M	1.7	−0.1
6	15	M	1.185	27	3	−3	−2.1	15	M	1	1.3
7	10	F	0.715	29	1	−0.7	−0.2	9	M	1.3	3
8	9	M	3.550	42	1	−1.7	−0.8	9	M	0.7	−0.9
9	13	M	3.550	40	1	−2.3	−0.8	13	M	1.7	1
10	11	M	1.960	36	4	−3	−1.9	11	M	0.3	NA
11	10	M	1.355	34	1	−1	−2.1	10	M	−1	−0.7
12	16	F	2.600	38	3	−3	−3	16	F	0.7	−1.3
13	16	F	1.140	28	4	−2.3	−1.2	16	F	1.7	−0.5
14	16	M	1.300	29	3	−2.3	−2.1	17	M	3	1.7
15	10	F	0.970	30	2	−3	−1.6	9	F	0	−1.1
16	11	M	1.000	31	2	−2	−1.5	11	M	0	NA
17	17	F	0.915	28	1	−1.3	−3	17	F	3	2
18	9	F	NA	31	3	−0.7	0.3	9	F	0.7	−0.5
19	10	M	1.055	30	2	1.7	0.9	10	M	−0.7	−0.5
20	10	M	1.255	30	3	−1.3	−1.1	10	M	−0.7	−0.6
21	10	F	1.418	32	2	−2.3	−1.3	9	F	−1.3	0.1
22	14	F	1.440	31	2	3	0.4	14	F	3	NA
23	12	M	0.630	27	4	0	−0.8	18	M	2.3	0.8
24	10	F	1.200	28	3	−1.7	1.2	9	F	1	1.1

Note: GMFCS: Gross Motor Function Classification System (level 1: the child walks without restrictions, level 5: self-mobility is severely limited even with the use of assistive technology; Palisano et al., 1997).
M: male, F: female.
NA: not available due to missing data.

factors such as age and gender. Age was chosen to be the continuous comparison variable and thus participants in the control group were selected if they were within the specified age range of children in the CP group (i.e., Age ± 2 years) (Last, 1995). The CP group included 24 participants (12 boys) diagnosed with spastic CP, aged 9–20 years ($M = 13$, $SD = 3.51$). Results were compared to those of a control group of 24 TD participants (13 boys) aged 9–18 years ($M = 12.92$, $SD = 3.52$). Children and adolescents were divided into two age groups (12 participants in each group): age ≤11 and age ≥12, according to the developmental trajectory previously described regarding cognitive procedural learning.

Prior to this study, we conducted a pilot study using TD controls and found that children at the age of 8 were unable to understand the instructions of the PCL task. Therefore, inclusion criteria for all children were a minimum age of 9 years, sufficient motor skills for tapping on a computer keyboard (which was examined via a pretest prior to performing the task, in which the children were asked to tap on two adjacent keys on the computer keyboard), no visual impairments that might interfere with performance on a computer task and comprehension of the study instructions. The participant's level of motor impairment was evaluated by trained physiotherapists using the Gross Motor Function Classification System (GMFCS) (Palisano et al., 1997). The CP diagnosis of the research group was verified via medical records. A detailed description of the participants is presented in Table 2.

The participants in the TD control group were recruited from several mainstream schools, whereas the participants in the research group were recruited from several mainstream schools, through special education schools, and from a Department of Pediatric Rehabilitation in a hospital in central Israel. It should be noted that some of the participants in the current study (20 out of 24) also participated in a research on motor procedural learning using the SRT previously reported (Gofer-Levi et al., 2013). However, the number as well as the composition of the participants in the PCL vs. the SRT tasks was not identical. Various reasons account for this discrepancy: an inability to understand the instructions of one task but not the other, difficulty in motor response needed for the motor SRT task but not for the PCL task, or due to cancelation of one of the two study sessions.

All procedures were approved by the Ministry of Education and by the hospital Institutional Review Board and were in compliance with ethical standards. Informed consent was obtained by the children's parents prior to participation.

2.2. Materials and procedures

Participants in both groups were tested individually, in a quiet room either at their school or at the rehabilitation unit. All participants performed the Raven's Colored Progressive Matrices/Raven's Standard Progressive Matrices (Pueyo, Junque, Vendrell, Narberhaus, & Segarra, 2008; Raven, 1984; Raven, Raven, & Court, 2000) and the Children Category Test/Booklet Category Test (Boll, 1993; DeFilippis & McCampbell, 1997), according to the participant's age, and a probabilistic classification learning (PCL) task. Prior to performing the PCL task, participants were given a sample task, by means of which we were able to make sure the instructions were clearly understood.

2.2.1. Raven's Colored Progressive Matrices (RCPM)/Raven's Standard Progressive Matrices (RSPM)

The RCPM has classically been used to measure global cognitive performance in terms of mental age and non-verbal intelligence, but has also been found capable of obtaining a measure related to linguistic, visuoperceptual, and memory cognitive functioning in individuals with CP. The RCPM is suitable for persons with severe motor impairment and speech limitations (Pueyo et al., 2008). The test is addressed to children aged 5–12 years. It is composed of 36 items divided into 3 sets, with each item containing a pattern with a missing piece. The child has to choose the correct missing piece out of 6–8 optional pieces, by either pointing to that piece or saying the number that represents it (Raven, 1984).

The RSPM is the original test on which the RCPM is based on. This version is suited for ages 12 years and older. It is composed of 60 items divided into 5 sets (Raven et al., 2000).

Each child's Z score was calculated based on population data.

2.2.2. Children Category Test (CCT)/Booklet Category Test (BCT)

The CCT is a tool designed to evaluate non-verbal learning and memory, the formation of concepts and problem solving ability in children aged 5–16 years. In addition, the CCT provides information about the child's ability to change problem solving strategies, develop alternative flexible solutions and profit from experience, and thus is considered a standardized measure to test EF. Thanks to the non-verbal nature of the tool, it is possible to assess the child's conclusion-drawing abilities in a manner that is unrelated to level of verbal articulation (Boll, 1993).

The CCT is composed of 5 subtests and a total of 80 items. The items composing each subtest are related by a specific principle, which changes from one subtest to another. The child has to identify the principle and apply it to the following items in that particular subtest. The items in the test are meant to make the child think about one of four numbers (1/2/3/4). The child is instructed to point to this number on the response card placed in front of the stimulus booklet or say the number verbally. An immediate feedback is received (right/wrong). In the last subtest, the child is asked to remember and apply the principles from previous subtests (Boll, 1993).

The BCT is parallel to the CCT, suitable for ages 15 years and up. The BCT is composed of 7 subtests and a total of 208 items. Instructions and feedback are the same as in the CCT. Once again, in the last subtest the participant is asked to remember and apply the principles from previous subtests (DeFilippis & McCampbell, 1997).

2.2.3. Probabilistic classification learning (PCL) task

The SuperLab Pro software version 2.0 (Cedrus, Inc.) was used to run the task on a laptop with a colored 15.4 in. screen.

The paradigm used in this study was similar to that described by Shohamy et al. (2004). In the PCL task, participants were told they are working in an ice cream shop and were asked to predict the flavor of ice cream (''chocolate'' or ''strawberry'') that the client entering the shop wanted. The clients consisted of the basic Mr. Potato Head figure (head with black eyes, red nose, mouth, white arms and green feet) on which one to three out of four different features (i.e., cues) were added (cue 1 = black hat, cue 2 = brown mustache, cue 3 = yellow eyeglasses, cue 4 = blue bow tie). See Figure 1 for examples of task pictures.

Fourteen different ''*Potato Head Clients*'' were created, each with a unique set of cues. Two hundred trials were constructed from these fourteen patterns (for a detailed description of the probability structure of the task see Appendix A). The ''*Potato Head Clients*'' were presented in a randomized, but fixed order, for all participants.

Once the participants gave their prediction, feedback was given in several ways. The recorded variable was accuracy (i.e., the percentage of optimal responses) and not reaction time, making this task extremely suitable for people with motor disabilities.

In addition, responses were given using two distant keys on the computer keyboard, in order to reduce possible errors related to dexterity difficulties. The participant's response was defined as optimal if it matched the outcome that was most often associated with the ''*Potato Head Client's*'' ice cream of choice across the course of the experiment. For example, if pattern 1 was most often associated with a ''chocolate'' decision, a ''chocolate'' response was considered optimal for that pattern, even though on several trials the correct response was ''strawberry''. The percentage of optimal responses was computed in 4 blocks of 50 trials. Optimal response was undefined for four of the patterns, which were equally or almost equally associated with each outcome.

Upon completing the task, participants were questioned in order to assess the acquisition of declarative knowledge (i.e., ''Did you notice anything while performing the task? Was there a particular feature that was associated with a specific flavor of ice cream?''). Thus, in addition to performance on the task, participants were qualitatively evaluated as having acquired declarative knowledge or not.

2.2.4. Analysis

The results were analyzed using the SPSS program, version 19.0 (2010). Descriptive statistics were used to characterize the groups. Pearson correlations were calculated between score on the Raven's Progressive Matrices Test and the level of improvement (i.e., learning, calculated as the delta between the score on block 4 and that of block 1). In addition, partial correlations were calculated between EF as well as GMFCS and the level of improvement.

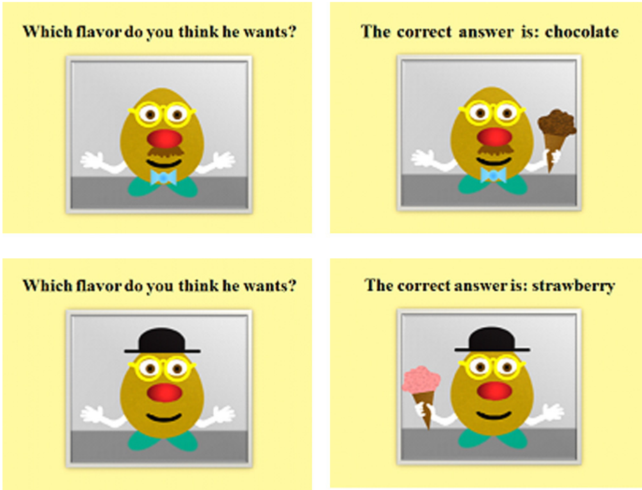

Fig. 1. Examples of the different Mr. Potato Head figures (*Note*: all the models of Mr. Potato Head were created by and received from Dr. Shohamy and her lab) in the PCL task, and their ice-cream of choice.

A mixed analysis of variance was conducted in order to examine the effect of group (CP, TD), age (age $\leq$11, age $\geq$12), and learning (block 1 to 4) on performance of the PCL task, with Raven's score as a covariate. In addition, a chi-square analysis was conducted in order to examine independence between group (CP, TD) and declarative knowledge of cue-outcome associations (yes, no).

The level of significance was set at $p < 0.05$.

3. Results

3.1. The relationship between intelligence and performance on the PCL task

In order to rule out the effect of intelligence on performance, we examined differences between the two groups on the score of the Raven Test. While there were no differences in the age and gender of the CP and TD groups, the TD group demonstrated significantly higher non-verbal IQ Z scores (Raven) ($M = 1.36$; $SD = 1.76$) compared to the CP group ($M = -1.75$; $SD = 1.56$), [$t(46) = -6.471$, $p < 0.001$]. There were no significant correlations between non-verbal IQ Z scores and the level of improvement (the delta between the score on block 4 and that of block 1) in the CP group [$r(24) = 0.084$, $p > 0.05$] nor in the TD group [$r(24) = 0.086$, $p > 0.05$]. In addition, no significant correlations between non-verbal IQ Z scores and the level of improvement were found in either the young participants [$r(24) = -0.199$, $p > 0.05$] or in the older participants [$r(24) = 0.261$, $p > 0.05$]. It appears that improvement in the PCL task in both groups was not related to non-verbal IQ, as measured by the Raven Test. Nevertheless, with differences in intelligence between the two groups, we added the Raven test score as a covariate in all analyses of the PCL task. The assumptions for ANCOVA were met. In particular, the homogeneity of the regression effect was evident for the covariate, and the covariate was linearly related to the dependent measure.

3.2. Executive function and performance on the PCL task

EF was not related to the level of improvement on the PCL task in the TD group, [$r(24) = -0.120$, $p > 0.05$], nor in the CP group, [$r(24) = 0.001$, $p > 0.05$]. In addition, no significant correlations between EF Z scores and the level of improvement were found in either the young participants [$r(24) = -0.189$, $p > 0.05$] or in the older participants [$r(24) = 0.061$, $p > 0.05$].

3.3. Level of motor impairment and performance on the PCL task

When controlling for non-verbal IQ, no significant correlation was found between severity of motor impairment (GMFCS) and the level of improvement [$r(21) = 0.113$, $p > 0.05$].

3.4. Performance on the PCL task

The results revealed a main effect for learning [$F(3,129) = 10.139$, $p < 0.001$, $\eta^2 = 0.191$], indicating that participants in both groups improved in the percentage of their optimal responses through performance on the task. Age effect, unlike group effect, reached significance, [$F(1,43) = 7.252$, $p = 0.01$, $\eta^2 = 0.144$] and [$F(1,43) = 0.079$, $p > 0.05$, $\eta^2 = 0.002$], respectively. In addition, there was a significant interaction between age and group [$F(1,43) = 5.132$, $p < 0.05$, $\eta^2 = 0.107$] as can be seen in

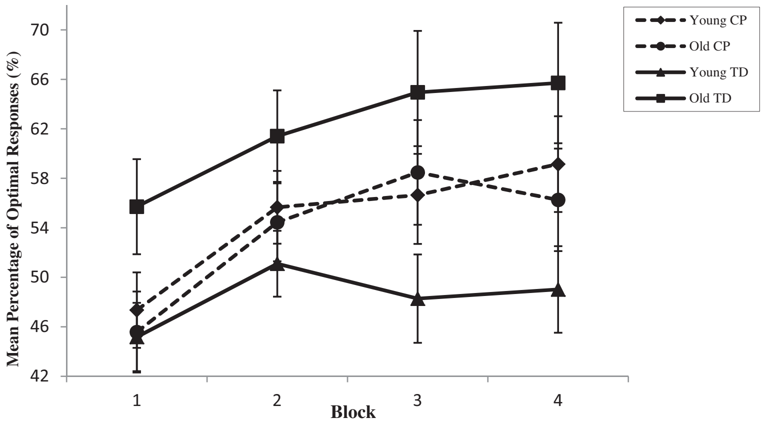

Fig. 2. Mean percentage of optimal responses per block by age for the CP and the TD group. Mean percentage of optimal responses and standard errors of the older (age ≥12) and younger (age ≤11) children for both groups in the four blocks of the PCL task. In the CP group, no significant difference can be seen between the two age groups, yet in the TD group the older children display a significantly higher mean percentage of optimal responses than younger children.

Figure 2. Overall, the older participants made a higher percentage of optimal responses ($M = 58.07$, $SE = 1.74$) compared to the younger participants ($M = 51.55$, $SE = 1.74$). However, when examining the source of the interaction, a significant age effect was found only for the TD group [$F(1,21) = 4.685$, $p < 0.05$, $\eta^2 = 0.182$], indicating that the percentage of optimal responses in the TD group was higher for the older participants compared to the younger participants. No significant effect for age was found in the CP group [$F(1,21) = 057$, $p > 0.05$, $\eta^2 = 0.003$], suggesting that, unlike TD participants, no developmental improvement in performance on the probabilistic task was found in children and adolescents with CP (Fig. 2). In addition, no significant difference was found between the young TD children and the young children with CP [$F(1,21) = 0.817$, $p > 0.05$, $\eta^2 = 0.037$].

No significant interaction was found between group and learning [$F(3,129) = 0.223$, $p > 0.05$, $\eta^2 = 0.005$], nor between age and learning [$F(3,129) = 0.683$, $p > 0.05$, $\eta^2 = 0.016$], on performance on the PCL task. In addition, the 2 × 2x4 interaction between group, age, and learning did not reach significance [$F(3,129) = 0.317$, $p > 0.05$, $\eta^2 = 0.007$].

As can be seen in Figure 2, a significant age effect was found only for the TD group, indicating that the percentage of optimal responses in the TD group was higher for the older participants compared to the younger participants. Yet, an unexpected above chance level performance was demonstrated among the older TD participants in the initial block (mean percentage of optimal responses = 57.74, $SE = 2.7$), indicating that the older TD controls learned the PCL associations relatively early in the task. This effect was not demonstrated in the young TD group. Thus we conducted a follow up analysis on performance only for the first block, in order to reveal if a learning curve does exist in the older TD group. For this purpose the first block of the PCL task was divided into two equal halves (each consisting of 25 trials). We conducted a 2 × 2 mixed ANCOVA for the TD group with age (age ≤11, age ≥12) as a between-subjects variable, initial learning (block 1) of the PCL task (two halves) as a within-subjects variable, and Raven's score as a covariate. The age by initial learning interaction was insignificant [$F(1,21) = 1.016$, $p > 0.05$, $\eta^2 = 0.046$] (see Figure 3). Since this is a probabilistic task, we would have expected a chance level initial performance among all participants.

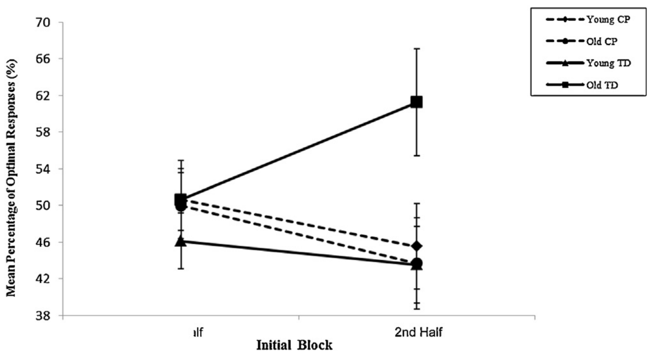

Fig. 3. Mean percentage of optimal responses in the two halves of block 1 by age for the CP and the TD group. Fig. 3 Mean percentage of optimal responses and standard errors of the older (age ≥12) and younger (age ≤11) children for both groups in the two halves of the initial block of the PCL task. In the CP group, no cue-outcome associations were obtained over the two halves of the initial block. In addition, the two age groups performed at a similar level. Similarly to the CP group, the younger TD children failed to learn the cue-outcome associations over the two halves of the initial block. However, the older TD children display an improvement in the learning of cue-outcome associations within the initial block.

We sought to find a plausible explanation for the higher than expected initial performance of the older TD group, and wondered whether IQ, previously held as a covariate, was responsible for this performance and thus for the insignificant interaction. Therefore, we decided to conduct the same analysis without holding Raven's non-verbal IQ score as a covariate. Under these circumstances, a marginal age by initial learning interaction was found [$F(1,22) = 4.396$, $p = 0.05$, $\eta^2 = 0.167$]. Examining the source of the interaction revealed a significant initial learning effect only for the older group [$F(1,11) = 4.812$, $p = 0.05$, $\eta^2 = 0.304$], but not for the younger group [$F(1,11) = 0.410$, $p > 0.05$, $\eta^2 = 0.036$], indicating that, unlike the younger TD children, the older TD group started learning cue-outcome associations within the first block, between the first half ($M = 52.09$, $SE = 2.95$) and second half ($M = 62.76$, $SE = 5.74$). The discrepancy between the two analyses indicates that differences in non-verbal IQ were related to the differences in initial learning in the TD group.

Finally, the CP and TD groups did not differ in acquiring declarative knowledge of cue-outcome associations [$\chi^2(1) = 1.279$, $p > 0.05$].

4. Discussion

In the current study we examined cognitive procedural learning among children and adolescents with spastic CP using the PCL task. In addition we aimed to examine the effect of individual differences in age, severity of motor impairment (GMFCS level) and in cognitive abilities such as IQ and EF, on their performance.

Our results demonstrated that with repeated trials, all participants improved in performance on the PCL task. Their overall predictions became more accurate with repeated exposures, with the most significant improvement noted for the older TD children from mean performance at chance level (50%) to about 64% by the last block of trials. Additionally, a significant interaction was found between group and age for the TD group but not for the CP group, in which older children with CP performed at a similar level to that of younger TD and younger CP children. We did not find a significant effect for the level of motor impairment (GMFCS), nor for the cognitive abilities (IQ and EF) on performance on the PCL task. Yet, due to a significant difference in IQ levels between the CP and TD groups, IQ was held constant across the analysis.

Improved performance from repeated exposures is the hallmark for procedural learning as a sub-domain of implicit learning. Our current results indicate that the basic mechanisms of such learning are operating in children with CP as well as in TD children. However, previous studies of cognitive procedural learning with TD children showed that older children demonstrate higher initial levels of performance and faster improvement rates compared to younger children (Ahonniska et al., 2000). The results of the current study are in agreement with these findings regarding TD participants, hence, making the specific PCL task used in the current study age sensitive. But, unlike TD children, no significant developmental improvement in performance was found among children and adolescents with CP. Initial performance gains of the older TD controls occurred within the first block, whereas older participants in the CP group gradually improved throughout the entire task, and never reached the performance level of their TD counterparts. Interestingly, looking into the scores of all groups in the initial block suggests that not only that the older TD were the only ones to improve within the first block, the remaining three groups showed a non-significant subtle decrease in optimal responses. However, this finding should be interpreted cautiously due to the relatively small sample size in the current study. In addition, it is possible that children and adolescents with CP need a prolonged learning period in order to stabilize the probabilistic nature of the task.

The lack of an age effect in a group of children with CP was reported in our previous study using a relatively simple motor sequence learning task (Gofer-Levi et al., 2013). However, in contrast to the current results, the lack of age effect on the SRT task was found in the CP as well as in the TD group. Interestingly, had we compared performance on the PCL task only between young children with CP and TD children, we would have wrongly concluded that the learning rate, as well as the performance level of these two groups of children, was identical. Yet the more reliable picture was revealed only when relating to a wider age range, which demonstrated the difference in cognitive procedural learning abilities between participants with CP and their healthy peers. It may be that as they grow, children with CP demonstrate a deficit in procedural learning ability hinting to a basic impairment in the maturation of the neuroanatomical substrates that support this type of learning (Giedd, 2004; Luna et al., 2001). However, although the age range and average were similar between the comparable age groups, there was a slight difference in the representation of different ages within the young age groups (i.e., TD: 9 yr – $n = 6$, 10 yr – $n = 4$; CP: 9 yr – $n = 2$, 10 yr – $n = 8$). Given this difference, it may be that the lack of a significant difference between the young and old CP groups is related to the different age composition. Yet, due to the fact that the older TD children had significantly higher scores than all other subgroups, it seems unlikely that the small difference in age composition accounts for this lack of developmental difference. Thus, when comparing the performance of children and adolescents with CP to that of TD peers on procedural learning tasks, it is important to take into account the type of task as well as the age of the individual.

The developmental differences in cognitive abilities presented in our study might be seen as a possible modification of the "*Matthew Effect*" (i.e., "the rich get richer and the poor get poorer") (Stanovich, 1986), in which the adolescents with CP lagged behind their TD peers and performed at a relatively *younger age level* even ten years apart. One might wonder if administering the task at an older age would yield results similar to those of TD adolescents. However, we assume that the likelihood of such delayed developmental effect is relatively low, since the age interval in our study was approximately ten years, increasing the probability that older participants had already reached adult levels of brain maturation.

In addition, we found that at younger ages, children with CP performed relatively close to their counterparts. Yet, since the average level of performance in both groups was close to chance (i.e., a mean of 50% optimal responses, see Fig. 2) it is possible that the PCL task was too difficult for the younger children and that these results simply reflect a similar guessing probability. Cross-sectional or longitudinal studies with yearly age-intervals may provide better understanding of this developmental aspect of cognitive procedural learning.

The finding that children with CP have lower scores on the Raven's Test compared to TD children (Ahonniska-Assa et al., 2012) was replicated in the current study. However, according to the current results, it seems that IQ does not affect the ability to learn the cue-outcome associations altogether. This finding supports previous reports in which performance on a probabilistic learning task was weakly related to psychometric intelligence, as measured by the Raven's Test (Kaufman et al., 2010). It appears that the impaired performance demonstrated by children and adolescents with CP on the PCL task was not significantly related to their lower scores on the Raven's Test. However, the relation between IQ and performance on various cognitive tasks among children with developmental disabilities is controversial, with some researchers suggesting that IQ scores in neurodevelopmental disorders are confounded with/or by the condition, and can never be separated from the effects of the condition (Dennis et al., 2009).

EF abilities, as examined in the current study using the Children/Booklet Category Test, were not related to performance on the PCL task. This is in agreement with findings that procedural learning operates in an automatic fashion once relatively low-level perceptual attention is selectively allocated to the appropriate stimuli, without necessarily requiring executive attention (Kaufman et al., 2010). However, the relation between other components of EF (such as working memory) and performance on the PCL task should be examined before concluding that such a relation does not exist.

In addition, unlike findings of a general correlation between severity of motor deficit and cognitive abilities in children with spastic diplegia (Ahonniska-Assa et al., 2012; Fennell & Dikel, 2001), but similar to results obtained in motor sequence learning tasks (Gagliardi, Tavano, Turconi, Pozzoli, & Borgatti, 2011; Gofer-Levi et al., 2013), severity of motor impairment, as classified by the GMFCS, was unrelated to the level of improvement in the PCL task and, hence, to the level of ability in procedural learning at large.

5. Limitations and future directions

The current study has some limitations. The first major limitation regards the relatively small sample of children and adolescents with spastic CP. Such a limitation is often a problem in studies amongst children with developmental disabilities, increasing the likelihood of a statistical type II error. However, we aimed to overcome such potential bias by choosing a relatively homogeneous sample (i.e., spastic CP), thereby reducing the variance and contributing to the reliability of the results. Furthermore, the effects seen even in this small sample were robust enough to support the above mentioned assumptions. In addition, when using hard-to-reach clinical samples as in the current study, comparing findings regarding the lack of age effect as well as the lack of motor impairment effect with previous studies on procedural learning among the CP population (Gagliardi, Tavano, Turconi, & Borgatti, 2013; Gagliardi, Tavano, Turconi, Pozzoli, & Borgatti, 2011) may also increase the reliability of the current results.

Secondly, although the PCL task used in the study was chosen due to its low perceptual loading, we cannot rule out possible differences between the two groups in performance due to difficulties in detecting changes in the visual components of the task. Thus, a follow up study could be conducted using an updated eye-tracking device, which might be useful in monitoring differences in visual perception and visual scanning among participants with CP. Thirdly, it should be acknowledged that the current PCL task required allocation of attention to different cues related to the specific task, i.e., *Mr. Potato Head* choices of ice cream flavor. Thus, the difference in performance found between the CP and control groups might be related to problems in attention abilities reported in previous studies on children with CP (Ahonniska-Assa et al., 2012), which were not measured in the current study.

Lastly, it should be noted that in this preliminary study, we did not conduct an imaging protocol; hence we relied on the diagnosis of bilateral spastic CP to provide some 'anatomical' stratification for the group, based on the common underlying mechanisms for the development of spasticity in the developing brain (Rosenbaum et al., 2007), but not the specific anatomical location of the brain lesions in our particular group of children. Clarification of possible neurological networks in CP that may impact cognition and learning abilities is needed. Combining structural and functional brain imaging with clinical evaluation of cognitive procedural learning abilities (such as PCL) in CP is needed in future studies.

6. Conclusions

In sum, to our knowledge, this is the first study to address the issue of cognitive procedural learning among children and adolescents with CP. The current results can be seen as an expansion of our previous findings, in which the implicit aspects of a relatively simple motor procedural learning task were significantly impaired in children and adolescents with CP (Gofer-Levi et al., 2013). We believe that understanding the unique aspects of the impairment in procedural learning among children and adolescents with CP and characterizing their learning curves could help rehabilitation and educational professionals to plan more efficient, knowledge-based interventions. Comprehensive insight into the developmental dimensions of the various tasks involved in procedural learning, which govern so much of what we actually, unknowingly do in every-day life, could help foresee future progress in our endeavors for people with disabilities.

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Appendix A

The probability structure of the Mr. Potato Head PCL task[a].

Pattern	Cue 1	2	3	4	Probability *P* (pattern)	Frequency	*P* (chocolate)
1	0	0	0	1	0.095	19	0.89
2	0	0	1	0	0.045	9	0.78
3	0	0	1	1	0.130	26	0.92
4	0	1	0	0	0.045	9	0.22
5	0	1	0	1	0.060	12	0.83
6	0	1	1	0	0.030	6	0.50
7	0	1	1	1	0.095	19	0.89
8	1	0	0	0	0.095	19	0.11
9	1	0	0	1	0.030	6	0.50
10	1	0	1	0	0.060	12	0.17
11	1	0	1	1	0.045	9	0.55
12	1	1	0	0	0.130	26	0.08
13	1	1	0	1	0.045	9	0.44
14	1	1	1	0	0.095	19	0.11
Total					1.00	200	

[a] Shohamy et al., 2004.

Note: On each trial, one of the 14 possible combination of cues (cue 1 = black hat, cue 2 = brown mustache, cue 3 = yellow eyeglasses, cue 4 = blue bow tie; 1 representing the presence of the cue, 0 representing the absence of the cue) could appear, with the probability *P* (pattern). Each combination of cues predicted a chocolate outcome with the probability *P* (chocolate) and predicted a strawberry outcome with the probability of 1 − *P* (chocolate) (Shohamy et al., 2004).

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