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Age differences in cognitive skill learning, retention and transfer: The case of the Tower of Hanoi Puzzle☆

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A B S T R A C T

The current study aimed to investigate cognitive skill learning using the Tower of Hanoi Puzzle (TOHP). This study expanded use of the TOHP to measure baseline performance, learning rate, offline learning (following overnight retention), and transfer, comparing two age groups (Grades 3 and 6) of participants ($n = 60$). Several measures were analyzed from 14 trials with the TOHP over two sessions: accuracy, processing speed, and planning. Findings revealed a trade-off between accuracy and time in both baseline performance and the learning phase for both groups, whereas the results for offline learning indicated an advantage for the older group in planning after a night's sleep. Transfer seemed to be most affected by age as reflected in the younger group's more shallow learning and limited problem schema acquisition, which resulted in fewer long-lasting effects compared to the older group. Findings are consistent with the current literature on frontal lobe and executive function development.

1. Introduction

Skill learning is a well-researched educational psychology topic. It is broadly described as the improvement of a skill over time as a function of practice. The process of skill acquisition begins with the acquisition/learning phase which includes the first engagement with the task (known as baseline performance), and proceeds with repeated practice of the procedure. This phase is accompanied by rapid improvements in performance that can be seen within seconds to minutes. The improvements during initial task practice follow a curve, where performance gradually reaches an asymptote (i.e., power function), and with sufficient practice the learned skill could reach automaticity (Stickgold & Walker, 2005). In this context, automaticity refers to a shift from controlled performance to more efficient performance with reduced demands on attention (Shiffrin & Schneider, 1977) and a corresponding shift in brain networks that support performance (Chein & Schneider, 2005; Jueptner & Weiller, 1998). Skill learning and mastery are usually tested by measuring accuracy and completion speed during the learning phase of a repeatedly presented task (Moscovitch, Goshen-Gottstein, & Vierzen, 1994).

1.1. Skill learning

Previous research on the development of skill learning has frequently employed the Serial Reaction Time (SRT), and other motor learning tasks which are commonly used perceptual task for assessing sequence learning (e.g. Meulemans, van der Lindenm, & Perruchet, 1988). Findings from research using this paradigm has provided evidence for the view that age does not play a role in the context of perceptual skills learning tasks, as numerous studies employing the SRT task demonstrated non-significant differences between groups of children and adults (e.g., Meulemans et al., 1988; Thomas & Nelson, 2001). Further studies examining motor skill learning in children and early adolescents, with an emphasis on learning benefits found similar evidence that implicit skill learning is not developmentally linked (Dorfberger, Adi-Japha, & Karni, 2007; Fischer, Wilhelm, & Born, 2007; Savion-Lemieux, Bailey, & Penhume, 2009). The goal of this study is to assess the role of age in a cognitive skill learning task in two age groups spanning childhood and early adolescence. These two specific age groups were selected because brain structure and function undergo significant maturation between these two age periods; namely, prefrontal systems are immature during early childhood, yet begin to emerge during early adolescence (Huttenlocher & Dabholkar, 1997).

Skill learning can also be assessed via cognitive skill learning tasks (Beaunieux et al., 2006). When such a task is employed just one time, it primarily measures executive functions (Lezak, Howieson, Loring, Hannay, & Fischer, 2004), whereas its repeated administration over many learning sessions mainly assesses cognitive skill learning (Beaunieux et al., 2006). Moreover, multiple engagement cognitive skill learning tasks enable investigation of individuals' pre-learning planning ability and their post-learning improvements in offline learning, which means further improvements without any further learning, and transfer.

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A few research studies have employed cognitive tasks to examine skill learning in patient populations such as: amnesics (Cohen & Squire, 1980; Schmidtke, Handschu, & Vollmer, 1996; Winter, Broman, Rose, & Reber, 2001), patients with lesions to the basal ganglia (Vakil, Blachstein, & Soroker, 2004), Parkinson's (Vakil & Harishanu-Naaman, 1998) or frontal lobe patients (Guevara et al., 2012). In the above studies, cognitive skill learning tasks were used for typical populations serving as control groups for a population with a disorder (e.g., Vakil & Harishanu-Naaman, 1998).

To date, very few studies have documented the process of skill learning for typically developing children and adolescents using a cognitive skill learning task the latter is often used to assess cognitive abilities (e.g. problem solving). Examining skill learning using a repeatedly practiced cognitive task enables prediction of participants' learning abilities of abstract rules in addition to their baseline performance (which is measured by one time tasks). It also allows prediction of participants' post-learning abilities during offline learning and transfer.

1.2. The Tower of Hanoi task

One such task enabling assessment of high-order cognitive problem solving and learning of complex cognitive procedures is the Tower of Hanoi Puzzle (TOHP). In this task, participants are given a puzzle comprising three pegs and a stack of three to five differently sized disks (which determines the difficulty level) placed on one peg forming a conical shape. Participants are asked to replicate this conical stack on another peg while following a set of simple rules restricting the movement of disks from peg to peg (e.g., disks can be placed only on top of larger disks and moving one disk at a time). Successful performance of the TOHP thus requires a range of executive functioning abilities including planning skills, visual imagery or mental modeling, abstract thinking, working memory, self-monitoring, and self-correction skills. TOHP has been widely used as a single-time task to assess executive functioning abilities such as planning and problem solving as well as implicit learning (Guevara, Martinez, Aguirre, & Ganzales, 2012; Huizinga, 2006; Miller & Cohen, 2001; Ward & Allport, 1997; Zelazo, Muller, Frye, & Marcovitch, 2003). Planning a solution for the TOHP involves envisioning a course leading from the task's initial condition to the end goal, which includes a series of middle stages or sub-goals. These stages or goals are operated following an accurate mental representation of the key features of the problem or an internal depiction or recreation of the problem in working memory during problem solving (Alibali, Phillips, & Fischer, 2009). Specifically, solving the task requires sub-goal management, which refers to the process of recursively thinking ahead about the future consequence of each intermediate action. In addition, counter-intuitive moves—intermediate steps in the opposite direction from the target goal—were also found to play an important role in TOHP performance (Klahr, 1994). As intermediate goals are achieved, the targeted representation must be adjusted until obtaining the end goal (Karat, 1982).

The effect of age on cognitive skill learning is unclear. In our opinion a distinction should be made between administering the TOHP once and several times. When the TOHP was used as a single-time task to assess executive functions, performance was shown to develop with age, in line with children's increasing ability to control thoughts and actions as they grow older (Flavell, 1971; Siegler, 1983). This view is in accord with neuropsychological research that correlated TOHP performance with prefrontal lobe function and dysfunction (Lezak et al., 2004). In addition, the maturation of these brain regions seems to be parallel to the appearance of Piaget's stages of cognitive development (Fuster, 1997; Glosser & Goodglass, 1990; Goldstein & Green, 1995; Lezak et al., 2004).

The protracted course of cognitive development begins in early childhood around age 4, although problem solving efficiency has been shown to be still immature (Borys, Spitz, & Dorans, 1982; Bull, Espy, & Senn, 2004; Klahr & Robinson, 1981; Welsh, 1991). Better performance is seen in ages 7–8. However, successful performance of the task is most often achieved at ages 11–13 years (Ahonniska, Ahonen, Aro, Tolvanen, & Lyytinen, 2000; Bishop, Aamodt-Leaper, Creswell, McGurk, & Skuse, 2001; Borys et al., 1982; Spitz, Minsky, & Bessellieu, 1985; Spitz, Webster, & Borys, 1982), reflecting shorter planning time and fewer moves needed to complete the task.

1.3. TOH and skill learning

To the best of our knowledge, only one exploratory study attempted to examine the development of cognitive skill learning using the TOHP (Beaunieux et al., 2006). In this study the researchers administered the task to adults in four sessions of 10 trials separated by one day. Findings confirmed the existence of three phases during cognitive skill learning (cognitive, associative, and automated), showing that skill learning did indeed take place (in terms of both moves and time) and that it changed across the learning sessions.). However, this study did not examine the additional improvements that may occur during offline learning or transfer. Offline learning refers to the additional behavioral improvements that take place in the absence of any further rehearsal or experience (Javadi, Walsh, & Lewis, 2011). Offline learning occurs after a period of nighttime sleep, although additional enhancement may occur after several days. It appears that offline learning depends on participants' initial amount of practice before the offline period and that greater initial practice leads to better offline enhancement (Hauptmann, Reinhart, Brandt, & Karni, 2005).

Transfer—the application of knowledge acquired in one situation or context to another—is an additional skill learning benefit that is integral to solving problems in everyday, real-world situations (Wedman, Wedman, & Folger, 1999). When encountering a new task with a solution structure resembling a previous task, individuals are able to apply principles from the mental scheme acquired in the original learning setting to the new context, despite the new task's distinct features (Catrambone & Holyoak, 1989; Chen, 1999). Knowledge is said to be transferred when performance on the second task is similar to or better than baseline performance on the initial task (e.g., Gomez, Gerken, & Schvaneveldt, 2000). However, the degree of transfer is largely determined by the level of similarity or overlap between the initial situation and the new context (Chen & Mo, 2004). The TOHP is particularly suitable for assessing transfer ability because it includes variant tasks ranging from lower to higher similarity, such as the highly similar task of moving the disks from the first peg to the third instead of vice versa (as used in the current study) or the less similar task of receiving the disks in an upside-down conical stack with the opposite rule for movement (e.g., disks can be placed only on top of smaller disks).

In addition, because transfer involves adapting knowledge, not just applying it (Schwartz, Chase, & Bransford, 2012), failure to transfer is often caused by a lack of deep initial learning (Chi & VanLehn, 2012). In other words, when learners do not acquire the problem schema during practice, and when they fail to notice the similarity between the examples and the subsequent novel task, their transfer abilities are limited (Chen, 1999). Thus, a sufficient number of trials to ensure initial schema acquisition is necessary to enable transfer to occur. Similarly to Beaunieux et al. (2006) the participants in our study were given 10 trials in the first session, so that they would be able to leave the cognitive phase by the end of the first session before they are given an interval of 24 h preceding the offline learning and transfer.

1.4. The current study objectives

In line with previous research showing that single-time performance of the TOHP task (indicating executive functions) was mastered at ages 11–13 years, the current study examined cognitive skill learning in two groups—in childhood (third graders) and in early adolescence (sixth graders)—to trace the developmental transition to skill acquisition. The current study also extended knowledge on the potential long-term effects of skill learning by examining the cognitive skill learning rates, offline skill learning, and transfer effects, which have not been empirically studied for typically developing children using the TOHP.

The current study design included 10 consecutive trials using the TOHP in the first session and three consecutive trials using the same TOHP task in the second session (24 h later), followed by a fourth TOHP trial in the second session using a variant TOHP task (solving the puzzle from the third to first peg rather than from the first to third peg as performed for the prior 13 trials). This study design extended prior research in several ways, by comparing the two age groups not only for their single-time performance as a measure of executive functioning (Trial 1), but also for their skill learning rates (Trials 1 to 10), their offline skill learning (Trial 10 vs. Trial 11 performed 24 h later), and their transfer effect (Trial 13 vs. Trial 14 on a variant task). The current study included 10 TOHP trials in the first session in order to enable a sufficient amount of initial practice to elicit offline learning and transfer. In addition, participants were given three trials in the second session to practice their cognitive skills before assessing transfer abilities.

It is predicted that the sixth graders' group would perform better (with less moves and faster) than the third graders' group at baseline, offline learning and transfer phases. In contrast, both groups would display similar performance during the learning phase.

2. Materials and methods

2.1. Participants

The sample consisted of 60 participants: 32 third graders (age: $M = 8.5$ years, $SD = .39$); 15 boys and 17 girls, and 28 sixth graders (age: $M = 11.56$ years, $SD = .42$); 16 boys and 12 girls. All participants were native Hebrew speakers with no reported signs of sensory or neurological deficits/attention deficit hyperactive disorder as indicated by the teacher and the school counselor.

Participants were recruited from two urban elementary schools in the greater Tel-Aviv area serving families with middle–high socioeconomic status. The schools were randomly selected from a list of middle–high socioeconomic status schools in the greater Tel Aviv area. Participants and their parents signed informed consent forms prior to the beginning of the study and all methods and procedures were approved by the Institutional Review Board of Bar-Ilan University and the Israeli Ministry of Education.

2.2. Task and procedure

A computerized version of the TOHP task was used. Three pegs appeared on the screen, numbered 1–3 from left to right. Three disks were arranged according to size on the extreme left peg (#1), with the largest disk at the bottom and smallest at the top. Participants were told that the goal was to move the disks from the leftmost peg (#1) to the rightmost peg (#3) in a minimum number of steps while maintaining the following rules: Only one disk at a time could be moved; no disk could be placed on a smaller on; and the middle peg had to be used. The optimal solution for three disks requires seven moves, yet the software enabled participants to use as many moves as needed. The directions neither referred to planning time nor time per move. Participants used a keyboard to move the discs from one peg to another. The computer automatically measured the time and number of moves required until the participant solved the puzzle.

Participants were tested individually in a quiet room at the school using the researcher's laptop. As mentioned above, participants engaged with this TOHP task for 10 consecutive trials in Session 1 (Trials 1–10) and for three consecutive trials in Session 2 held 24 h later (Trials 11–13). In Session 2, Trial 14 used a variant TOHP task where participants were instructed to solve the puzzle from right to left (pegs #3 to 1) instead of left to right (pegs #1 to 3). Participants were not given any feedback during the task nor were they instructed to try to improve their performance on each consecutive trial. It is noteworthy to mention that two participants dropped out from the study as they did not show up for school the next day for health reasons.

3. Results

Three dependent measures were calculated to reflect various cognitive processes underlying TOHP performance. Number of moves to solve the puzzle was used to assess accuracy. Time needed per move was used to assess speed of processing. Time elapsed at first move was used to assess planning. Using these three dependent measures, four aspects of performance were analyzed and were compared for the two age groups as described above: (a) executive functioning (performance on Trial 1); (b) the cognitive skill learning rates (Trials 1 to 10 in the first session); (c) offline learning (the last trial in the first session vs. the first trial in the second session); and (d) transfer effects (Trial 13 versus Trial 14 in the second session).

3.1. Executive function: First trial

3.1.1. Accuracy

The number of moves needed for solving the TOHP in Trial 1 did not differ significantly between third graders ($M = 14.78$, $SD = 7.01$) and sixth graders ($M = 15.89$, $SD = 11.27$), $t(58) = .46$, $p > .05$.

3.1.2. Processing speed

The average time needed per move for solving the TOHP in the first trial was significantly longer for third graders ($M = 16.92$ seconds, $SD = 8.02$) than for sixth graders ($M = 7.13$ seconds, $SD = 4.16$), $t(58) = .5.81$, $p < .001$.

3.1.3. Planning

The time elapsed until the first move for solving the TOHP in the first trial was significantly longer for third graders ($M = 19.25$ seconds, $SD = 14.69$) than for sixth graders ($M = 11.07$ seconds, $SD = 12.43$), $t(58) = 2.31$, $p < .05$.

3.2. Learning rates: Trials 1 to 10 in first session

To compare the two age groups' learning rates over the 10 trials in Session 1, mixed ANOVA with repeated measures was used with Group (Grades 3 vs. 6) as a between-subject factor and with Learning (Trials 1 to 10) as a within-subject factor.

3.2.1. Accuracy

The minimum number of moves required for the completion of the task is 7. Fig. 1 presents the mean number of moves per trial required for solving the TOHP in each of the two age groups across the learning trials in both sessions. Overall, the age groups did not significantly differ in the number of moves required to solve the TOHP, $F(1, 58) = .29$, $p > .05$. The main effects of Learning trials reached significance, $F(9, 522) = 18.77$, $p < .001$. The Group by Learning interaction did not reach significance, $F(9, 522) = 1.14$, $p > .05$. As seen in Fig. 1, the two groups showed similar learning rates with regard to task accuracy.

3.2.2. Processing speed

Fig. 2 presents the mean time per move to solve the TOHP for the two age groups across the learning trials in the two sessions. Overall, the older group revealed a significantly faster time per move than the younger group, $F(1, 58) = 66.00$, $p < .001$. The main effect of Learning trials reached significance as well, $F(9, 522) = 81.15$, $p < .001$, as did the Group by Learning trials interaction, $F(9, 522) = 17.04$, $p < .001$. As seen in Fig. 2, the learning rate with regard to processing speed was steeper for the younger group than for the older group, probably

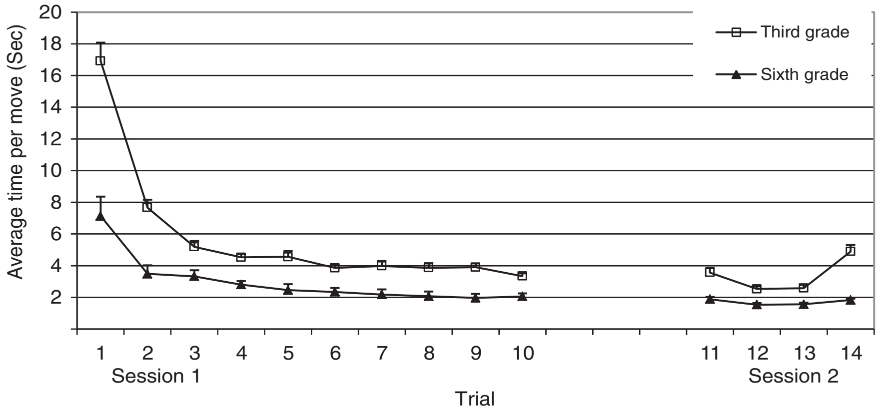

Fig. 1. Accuracy: Mean number of moves per trial (and standard deviations) for the third and sixth graders across the first session (baseline and learning rate) and the second session (offline learning and transfer effects).

due to a floor effect because the older group reached the maximum score at an earlier trial than the younger group.

3.2.3. Planning

Fig. 3 presents the mean time that elapsed until participants' first move for solving the TOHP for the two age groups across the learning trials in the two sessions. Overall, the older group made their first move significantly sooner than the younger group, $F(1, 58) = 28.20$, $p < .001$. The main effect of Learning trials reached significance as well, $F(9,522) = 39.53$, $p < .001$, as did the Group by Learning trials interaction, $F(9, 522) = 2.47$, $p < .01$. As seen in Fig. 3, the learning rate with regard to planning skills was steeper for the younger group than for the older group, probably due to the floor effect because the older group reached the maximum score at an earlier trial than the younger group.

3.3. Offline learning: Last trial of first session vs. first trial of second session

A mixed ANOVA with repeated measures was used to assess offline learning, with Group (Grades 3 vs. 6) as a between-subject factor and with Offline learning (Trial 10 vs. 11) as a within-subject factor.

3.3.1. Accuracy

No significant effects emerged for the mean number of moves per trial required for solving the TOHP, regarding main effect of Group, $F(1, 56) = .01$, $p > .05$, main effect of Offline learning, $F(1, 56) = 1.19$, $p > .05$, or the Group by Offline learning interaction, $F(1, 56) = .01$, $p > .05$. Thus, the data for number of moves in Trials 10 and 11 indicated no significant age-group differences, and both groups retained their performance level from the first to the second session after a night's sleep (see Fig. 1).

3.3.2. Processing speed

In the analysis of mean time needed per move, only the main effect for Group reached significance, $F(1, 56) = 34.66$, $p < .001$, indicating that the younger group was slower than the older group in both trials. The main effect for Offline learning, $F(1, 56) = .01$, $p > .05$, and the Group by Offline learning interaction, $F(1, 56) = 1.82$, $p > .05$, did not reach significance (see Fig. 2).

3.3.3. Planning

Analysis of the time elapsed until the first move revealed that both main effects and the Group by Offline learning interaction all reached significance: Group, $F(1, 56) = 40.62$, $p < .001$, Offline learning, $F(1, 56) = 12.03$, $p < .001$, interaction, $F(1, 56) = 10.06$, $p < .001$. As seen in Fig. 3, the older group began actively moving the disks sooner than the younger group and preserved this advantage in planning skills overnight. The interaction is due to the fact that it took the younger group but not the older group, longer time for the first move after delay compared to before delay.

3.4. Transfer effects: Trials 13 vs. 14

A mixed ANOVA with repeated measures was used to assess transfer of task learning to a similar but variant task, with Group (Grades 3

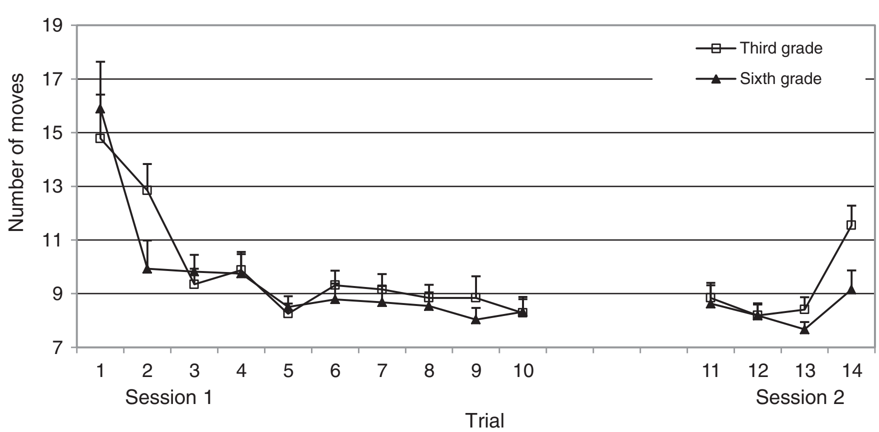

Fig. 2. Processing speed: Mean time per move (and standard deviations) for the third and sixth graders across the first session (learning rate) and the second session (offline learning and transfer effects).

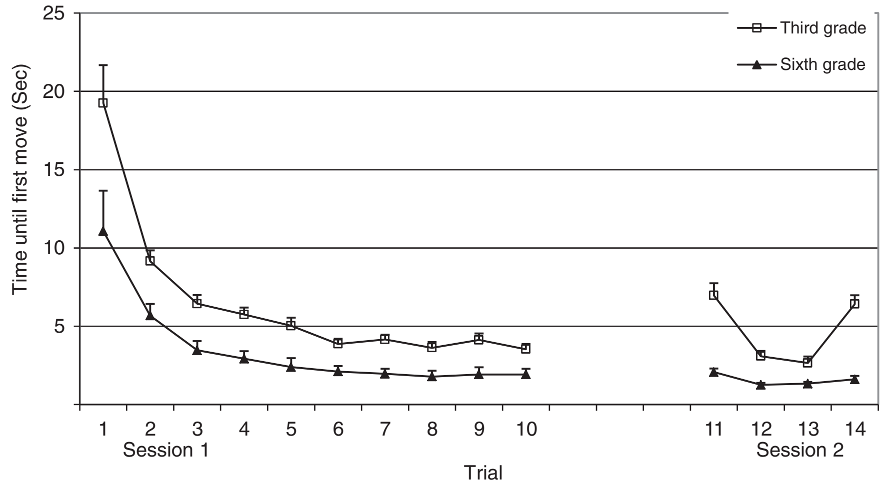

Fig. 3. Planning: Mean time elapsed until first move (and standard deviations) for the third and sixth graders across the first session (learning rate) and the second session (offline learning and transfer effects).

vs. 6) as a between-subject factor and with Transfer (Trial 13 vs. 14) as a within-subject factor.

3.4.1. Accuracy

Analysis of the number of moves per trial revealed significant main effects for Group, $F(1, 55) = 7.11$, $p < .05$, and for Transfer, $F(1, 55) = 14.61$, $p < .001$, but the Group by Transfer interaction did not reach significance, $F(1, 55) = 2.02$, $p > .05$. As seen in Fig. 1, overall the younger group needed more moves to accurately solve the TOHP, and the cost of transfer to a different version of the task (a rise in the number of moves) was the same for the two groups (see Fig. 1).

3.4.2. Processing speed

Analysis of mean time per move revealed significant main effects for Group, $F(1, 55) = 57.58$, $p < .001$, and for Transfer, $F(1, 55) = 24.68$, $p < .001$, as well as a significant Group by Transfer interaction, $F(1, 55) = 15.90$, $p < .001$. These results indicated that the younger group not only was slower in solving the task but also paid a higher cost (slowed processing speed) when transferring to a different version of the task, in comparison to the older group (see Fig. 2).

3.4.3. Planning

Analysis of the time elapsed until the first move revealed significant main effects for Group, $F(1, 55) = 64.08$, $p < .001$, and for Transfer, $F(1, 55) = 24.46$, $p < .001$, as well as a significant Group by Transfer interaction, $F(1, 55) = 17.59$, $p < .001$. These findings indicated that the younger group not only was slower in beginning to actively solve the task but also paid a higher cost (slower initial move) when transferring to a different version, in comparison to the older group (see Fig. 3).

3.4.4. Processing speed and accuracy correlation

In order to test whether there is a tradeoff between speed and accuracy three new scores were generated for each age group which reflect learning in terms of accuracy (number of steps on the 1st trial minus 10th trial) speed (time per move on the 1st trial minus 10th trial) and planning (time until first move in the 1st trial minus 10th trial). Separate Pearson product moment correlations between these three scores were analyzed for each group separately. The only correlation reached significance was that between speed and accuracy in the 3rd grade, $r(31) = -.59$, $p < .001$. The correlation between speed and accuracy in the 6th grade did not reach significance, $r(28) = -.22$, $p = .26$. These results suggest that the younger but not the older participant made a speed accuracy tradeoff.

4. Discussion

Previous research on the development of skill learning mainly employed the SRT task, which is a commonly used task for assessing implicit memory function. In the SRT task, a stimulus is in one of several locations and participants are required to respond as quickly and accurately as possible by pressing a button, not being aware that the sequence in which the positions are presented is not randomized. Data from these studies research studies have demonstrated non-significant or minor differences on SRT task between groups of children and adults demonstrates that children were slower to respond to sequenced blocks both in time and accuracy as opposed to adults (Lum et al., 2010; Mayberry, Taylor, & O'Brien-Malone, 1995; Meulemans et al., 1988; Thomas et al., 2004; Thomas & Nelson, 2001; Vinter & Perruchet, 2000).

The tower of Hanoi is a complex disk transfer task that requires high-level cognitive and problem-solving behavior. It has been traditionally applied to assess executive function abilities in a single trial (e.g., Flavell, 1971; Siegler, 1983). The current study extended it by applying this tool to investigate additional aspects of cognitive skill learning, including skill learning rates over repeated trials, offline learning, and transfer effects to a slightly variant task. It focused on typically developing 3rd and 6th graders by measuring processing speed, solution accuracy, and planning.

Altogether, in participants' baseline performance (Trial 1) and in their learning phase (Trials 1–10), a tradeoff between accuracy and time was evident for the younger group. That is, although the groups did not differ in the number of moves they needed to solve the puzzle (accuracy), they did differ in the length of time that passed before they began moving the disks and in the mean time they devoted to each move, favoring the older group. This pattern emerged both for their first encounter with the puzzle and across their 10 trials while attempting to minimize their moves for solving the TOHL.

Findings from the current study seem to indicate that cognitive skill learning at the baseline performance and learning phase on the TOHP develops between the ages of 8–9 and 11–12 years. Whereas previous (Bishop et al., 2001) studies have indicated a difference in the number of moves, in this study, similar to Ahonniska et al. (2000), it is seen in shorter planning time and time per move needed to complete the task. The faster speeds for the older group while maintaining accuracy suggest that these early adolescents were able to process the task efficiently and rapidly reach automaticity while moving the discs from one peg to another. Conversely, the younger participants may have been busier monitoring the online mental representation of information needed for the problem's solution (Welsh, Cicerelo, Cuneo, & Brennan, 1994), and therefore their performance was more exploratory and less fluent, and their learning was ineffective. The similar performance of the two groups in accuracy and the difference in speed is further supported by negative correlation between speed and accuracy which was significant for the younger participants only.

Prior research has provided multiple lines of evidence for the speed–accuracy tradeoff. Participants perform tasks accurately by reducing the speed of performance or they perform tasks quickly at a cost of making more errors (e.g., Bogacz, Wagenmakers, Forstmann, & Nieuwenhuis, 2010; Meyer, Irwin, Osman, & Kounios, 1988). The speed–accuracy tradeoff is often explained by the process through which participants accumulate information for responding to a given task. A participant starts to process a stimulus from an initial state of minimal information about the correct response to it. This state persists until a cognitive transition takes place, initiating a move. The participant makes a move when the accumulated information reaches a specified high threshold (Meyer et al., 1988). In the current study, what differed between third and sixth graders was the time taken in reaching the threshold level of information needed for initiating a response. While the six graders broke the task down into sub-tasks until the sub-task at hand was something that they knew how to solve, the third graders spent more time breaking the task down into sub-tasks and again into more sub-tasks before they knew how to solve it.

In contrast to previous studies that utilized the TOHP, this study also assessed the offline learning and transfer effects. The results of the offline learning phase showed a different pattern. After a night's sleep, participants in both groups were able to maintain their prior skill learning in terms of accuracy (number of moves to solve the puzzle) and processing speed (time per move); however, a clear advantage emerged for the older group regarding the speed of their first move. In other words, the sleep-dependent effects resulted in a longer planning phase for the younger children than they had previously shown in the last trial at the end of the prior session. It is possible that the older participants "remembered" how to do the puzzle rather than spend more time planning. Other researchers examining the offline learning of children following SRT and motor sequence learning presented inconsistent findings with regard to age. Dorfberger et al. (2007) and Meulemans et al. (1988) described no differences in implicit memory consolidation on SRT between groups of children and adults. Both Fischer et al. (2007), who used SRT, and Savion-Lemieux et al. (2009), who used the Multi Finger Sequence Task, reported an advantage for 10-year-olds and adults compared with 6- and 8-year-olds. These mixed results reinforce the significance of the distinction between perceptual and cognitive tasks (Vakil & Hoffman, 2004). In the current case, the complexity of the TOHP required participants to invest more time in planning future moves and retrieving information that was stored prior to the overnight retention interval.

Perhaps the most striking results of this study related to participants' performance in the transfer phase. Transfer requires abstract representation abilities (by forming a mental schema of the solution) and flexible thinking to enable generalization and application of the recursive law in a different context (Bull et al., 2004). In the present study, although the participants were given extensive training over a total of 13 trials in a very similar task, the third graders needed more moves to complete the task compared to sixth graders. In line with the definition of transfer as performance on the new task at the same or higher level as performance on the initial task (Gomez et al., 2000) only the older group revealed successful transfer when asked to switch their task solution to right-to-left instead of left-to-right. Findings also demonstrated an increase in the third graders' mean time per move and planning time until their first move when encountering the new right-to-left task. Inasmuch as transfer to a novel skill or version of the skill relies on the acquisition of abstract knowledge and mental flexibility (Bull et al., 2004), the finding that younger children were more vulnerable to poor transfer indicated that their skill learning was shallow (Chi & VanLehn, 2012). It seems that the third graders' learning process did not result in long-lasting mental flexibility that could ultimately lead to adaptation of their solution procedures to changing task demands and contextual factors. It could be argued that the sixth graders' solution schema contained more skill knowledge and knowledge about applicability of the solution principle than those of the third graders; thus, they were able to form more general rules that were not limited to the one context, thereby facilitating transfer (Chen, 1999). Perhaps development of the frontal lobes may account for such differences in performance between the two age groups, considering that the TOHP was found to be sensitive to frontal lobe functioning (Lezak et al., 2004). Finally, perhaps the structure of the practice sessions in the current study may have also played a role. Perhaps practicing the TOHP in the context of multiple task versions would have led to favorable adaptation over time by allowing learners to learn the task more deeply and to facilitate problem schema learning or abstract rule acquisition (Chen & Mo, 2004; Kantak, Sullivan, Fisher, Knowlton, & Winstein, 2011; Rosalie & Muller, 2012).

Findings from the current study seem to contrast with findings from SRT-based skill learning studies, which showed either minor differences or none between different age groups, and which concluded that the skill learning ability appears early in development and already reaches adult-level performance at that time (Meulemans et al., 1988; Thomas & Nelson, 2001). These gaps between the current TOHP study and prior SRT studies may be attributed to the nature of the tasks employed. The SRT is a perceptual motor skill learning task and the skills learned via the task and not easily articulated, whereas the TOHP is a complex cognitive task that becomes automatic with practice, yet participants can still articulate their goals and sub-goals during the task. It further requires participants to utilize abstract thinking, apply planning skills, and recursive law implementation. It could be argued that the development of the frontal lobe during the transition from childhood to early adolescence may account for the differences found here in the cognitive performance between the two age groups, as the TOHP has been found to be sensitive to the functioning of the frontal lobes (Lezak et al., 2004). In contrast, perhaps the brain structures and functions related to perceptual motor skills may be fully developed in childhood, thus precluding age-group differences. Future comparative research would do well to utilize brain imaging to further investigate these speculations.

In summary, the findings of the present study support the view that the cognitive TOHP task is sensitive to age. Although the age-related differences favoring the sixth graders were not pronounced in the number of moves they needed to complete the puzzle, the age groups' distinctions did emerge in the measures of time in almost all the different stages of the learning process (baseline, acquisition, offline, transfer). In other words, compared to the indices of processing speed and planning ability, accuracy was not affected so much by age. Furthermore, the phases of offline learning and especially transfer were found to be more sensitive than the learning phases to the effect of age. In the offline learning phase, neither age group benefited from the nocturnal interval; moreover, the younger group even regressed in the time they required to complete the task. This stands in contrast to previous studies using the perceptual motor skill-based SRT, which reported offline learning gains (i.e., Drosopoulos, Wagner, & Born, 2005). As for transfer, the current study exhibited more general skill acquisition on the part of the sixth graders, whereas the younger group's learning was more inflexible and resulted in an inability to transfer the skill to a new setting. Though both groups performed better than baseline and increased moves from trial 13 to trial 14, the younger participants needed more time. This result may be explained by the idea that for transfer to happen, construction of problem schema is required.

This study extends previous work by assessing age effects between childhood (mean age of 8.5 years) and early adolescence (mean age of 11.5 years) in a cognitive skill learning task. Most skill learning studies have employed perceptual tasks (Dorfberger et al., 2007; Fischer et al., 2007; Savion-Lemieux et al., 2009); yet, findings from this study point to the importance of using cognitive tasks to add key insights to complement understanding of skill acquisition, offline learning, and transfer. The age differences reported here are readily interpretable in terms of Piaget's (1964) theory of cognitive development, combined with the well-studied brain improvements that take place around the selected age groups. Recent advances in understanding the mechanisms responsible for brain networking (Chein & Schneider, 2005; Jueptner & Weiller, 1998) may account for the slower performance of the younger children. Beyond the theoretical contribution of the current study, the results may point to the possibility of using the TOHP as a tool for assessing various aspects of the learning process such as learning rate, offline learning and transfer.

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