BRIEF REPORT

Age Difference in Dual-Task Interference Effects on Procedural Learning in Children

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Abstract

The present study aimed to investigate the role played by explicit mechanisms during procedural learning in two age groups of children (7 and 10 years old), using a dual-task paradigm. To do this, we explored the effect of an interference task during the early and late phases of a mirror tracing learning task. The results showed a differential impact of the secondary task on the two age groups, but only during the first learning phase: the performance of 10-year-olds was affected by the second task, whereas in 7-year-olds no performance difference was found between the single- and dual-task conditions. Overall, our study suggests that there are differences in the amount of effortful processing that 7- and 10-year-olds engage at the beginning of the learning process: Procedural learning in young children is mainly implicit, as attested by its lesser sensitivity to an interference task, whereas high-level explicit mechanisms seem to contribute to the procedural performance of 10-year-old children. However, these explicit mechanisms, even if they have an effect on performance, may not have an impact on the learning curve because no difference in rate of acquisition was found between age groups. These findings are discussed in the light of classical conceptions of procedural learning.

*Keywords*: procedural learning, child, development, interference task, dual-task, mirror tracing task

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Classical conceptions of procedural learning postulate that skill acquisition involves a series of stages wherein knowledge is first stored in a declarative form and then converted into procedural knowledge (e.g., Anderson, 1982). According to this view, skills are mostly acquired through an explicit, attention-demanding learning mode (i.e., the learner develops explicit knowledge of how to execute the task). The cognitive processes involved at the beginning of learning are said to be "controlled" or “explicit,” with learning performance depending strongly on the availability of high-level cognitive mechanisms (such as working memory). With practice, the skill progressively becomes implicit and automatic, the attentional demands of the task decrease, and, in the end, the skill can be performed in a fully automatic mode, as attested by the fact that performance is unaffected by a concurrent secondary task (Chauvel et al., 2012).

This top-down conception has received experimental support from studies conducted in adults with perceptuomotor adaptation tasks such as mirror tracing (e.g., Kennedy, Patridge, & Raz, 2008). In this task, participants have to trace a figure with a pencil while seeing the action of their hand only in a mirror, which requires them to modify a well-learned association between vision and a motor behavior. There is evidence that cognitive resources play an important role in the initial learning phases of perceptuomotor adaptation tasks. For instance, several studies in adults have highlighted the involvement of executive functions (inhibitory control and working memory) in the learning of the mirror tracing task (Brosseau, Potvin, and Rouleau, 2007; Kennedy et al.). Eversheim and Bock (2001) confirmed the involvement of explicit processes in procedural learning, finding that a concurrent secondary task interfered with the early learning phase of a perceptuomotor skill.

From a developmental perspective, most studies on procedural learning in children have used implicit learning paradigms like the Serial Reaction Time task (e.g., Meulemans, Van der Linden, & Perruchet, 1998), showing that implicit learning is relatively age-independent. However, the applicability of the top-down approach to procedural learning in children—in other words, the role that explicit processes may play in procedural tasks at these ages—remains an open question. Given the immaturity of young children’s working memory and executive functions, how can the alleged efficiency of procedural learning in early childhood be reconciled with this top-down approach? Is the top-down approach to skill learning described in adults applicable to young children whose explicit mechanisms are still developing?

Because very few studies have investigated procedural learning in children with tasks like mirror tracing, little is known about the role played by explicit cognitive processes in such tasks during childhood. Previous studies focused on comparing the learning performance of children of different ages, but not on the processes underlying procedural learning. For instance, Ferrel-Chapus, Hay, Olivier, Bard, and Fleury (2002) tested the ability of children aged between 5 and 11 years, as well as a group of adults, to draw a figure without seeing their hand, and with a view of the scene that was rotated by 180°. The results showed differences in performance with age at the beginning of the learning process, but not in the acquisition rate. We recently explored the procedural learning in two groups of children (7- and 10-year-olds) and in a sample of adults, as well as the role played by executive functions during skill acquisition in these three groups (Lejeune, Catale, Schmitz, & Meulemans, 2013). As in previous reports, our results showed that age has an effect on performance in the initial learning phases, but also reflected a similar learning effect in the three groups. In addition, our results showed that inhibition played a significant role in the performance of 10-year-olds and adults at the beginning of learning, but not in that of 7-year-olds. This last result leads us to consider an alternative to the classical top-down conception of learning, according to which skill acquisition may operate at an implicit level from the outset (without the involvement of explicit processes) and that children may shift progressively during development from an implicit learning mode to a more explicit one (e.g., Karmiloff-Smith, 1992; Sun, Merrill, & Peterson, 2001). However, to the best of our knowledge, this “bottom-up” conception has not yet been empirically investigated in children using a procedural task like the mirror tracing paradigm. Therefore, it remains difficult to determine which processes, implicit or explicit, are active during skill learning in children, and, more specifically, how their involvement changes with the development of cognitive capacities during childhood.

The main objective of the present study was thus to investigate the role played by explicit mechanisms during the early stage of children's learning of a mirror tracing task. More specifically, we wanted to test the hypothesis that the mechanisms involved during learning differ according to the state of development of children’s cognitive capacities. To do so, we compared the effect of an auditory interference task on performance of a procedural task in two groups of children: 7-year-olds and 10-year-olds, chosen for the contrast in the level of maturity of their explicit mechanisms. The interference task was performed at the beginning of the learning of the procedural task. The introduction of an interference task (which demanded additional attentional resources) should affect explicit processes more than implicit processes, the latter being more automatic (Sun et al., 2001). Specifically, if explicit mechanisms are active at the outset of learning (Anderson, 1982), performing a concurrent secondary task should result in a performance deterioration during this phase. However, because we hypothesized that implicit processes may predominate in the first stage of learning in young children, our prediction in this case was different: the interference task should have a lesser effect in this age group. We predicted that (a) the interference task should have a greater effect on performance in 10-year-olds than in 7-year-olds; (b) the performance of 7- and 10-year-old children in the dual-task condition (when implicit processes prevail) should be equivalent, whereas the performance of younger children should be poorer than that of older children in the single-task condition (because older children could benefit from their ability to use controlled attentional resources—i.e., executive functions—in this condition). Finally, the interference task was also administered at the end of the learning process to ensure that the skill had been automatized (at this stage, performance should thus be relatively unaffected by the dual-task condition).

**Method**

**Participants**

A total of 75 right-handed children, divided into two age groups were tested: 38 7-year-olds (22 girls, 16 boys, *M*age = 7years 6months [7.6], range = 6.10–8.01), and 37 10-year-olds (22 girls, 15 boys, *M*age = 10.6, range = 9.11–11.03). Note that one 10-year-old child was excluded from the analyses because his completion time on the procedural task was more than 3 SD from the mean for his group. The local research ethics committee approved the study and we received parental informed written consent for all participants.

All children were Caucasian and attended primary schools in the French-speaking part of Belgium. There was no difference between age groups in mother’s education level (*p* > .05). Twenty percent of the children had a mother with a low level of education (less than 9 years), 32% a medium level (12 years), and 48% a high level (more than 12 years). No children had any history of neurological or psychiatric problems or learning disabilities. All performed above the fifth percentile on Raven’s Progressive Matrices (1998). Cognitive tasks were also administered to better characterize the children in terms of a set of high-level cognitive functions (inhibition, switching, and working memory; see Table 1 for test scores) The performance of the 7-year-old group was poorer than that of the 10-year-old group on explicit tasks measuring executive functions.

Table 1

Executive performance in the two age groups.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | 7-year-old children | | |  | 10 year-old children | | | *t*(73) | *p* |
| *Tests* | M | SD |  |  | M | SD |  |  |  |
| Inhibition  Stroop (interference index)  Simon task (interference index)  Switching  Flexibility (time in ms)  Flexibility (errors)  Working memory  Working memory (time in ms)  Working memory (errors) | 26.84  107.24  1323.11  5.35  1180.43  6.70 | 10.12  90.63  311.69  3.01  338.43  5.65 |  |  | 18.59  63.24  1001.43  3.46  923.51  3.51 | 6.02  53.34  212.11  2.65  239.57  3.99 |  | 4.27  2.55  5.19  2.87  3.77  2.80 | <.001  .01  <.001  .005  <.001  .006 |

*Note*. The following executive tasks were administered. [1] Inhibition skills were assessed using two tasks: the Interference Fruit Task (Catale et al., 2013) and the Simon Task (Nassauer & Halperin, 2003, adapted for children by Catale et al., 2011). An inhibition score (i.e., interference index) was calculated for the two tasks (time for interference condition – time for control condition). [2] The switching process was evaluated using the flexibility task from the TAP battery (Zimmerman & Fimm, 1994). [3] Working memory was assessed using an updating task (2-back task) from the TAP battery.

**Materials**

**Mirror tracing task.** A 5-point star with a 1-cm-wide outline was presented on a white sheet of paper fixed to a platform. A nearly vertical opaque barrier was positioned such that participants could see the paper sheet and their hand only through a mirror placed vertically in front of them. They were instructed to draw the contour of the star with a pencil using their dominant hand, reflected in the mirror, as quickly and accurately as possible without going outside the lines of the contour; doing so was defined as an error. To maintain a sufficient level of motivation, the task was presented as a game, with pictures of cars posted on the track; the children were told that they would “catch” the cars while passing over them with the pencil.

To familiarize themselves with the task, the children were first asked to trace the star using normal vision—i.e., without the mirror. The training phase (with the mirror) took place during two sessions, separated by a one-week delay.The task consisted of 20 trials (10 trials per session). For all trials, completion time (in seconds) and number of errors were recorded (following the methodology of Brosseau et al., 2007: 1 error was counted if there is an exit from the outline of >1 mm with re-entry ≤ 2 cm from the exit point; 2 errors were counted if the re-entry was more than 2 cm from the exit point; and 3 errors were counted if the edge of the outline was crossed several times at the same place).

**Interference tasks.** Six auditory tasks were presented in a pilot test to 10 children aged from 7–10 years old. Following the recommendations of several authors (e.g., Miyahara, Piek, & Barrett, 2006; Tsai, Pan, Cherng, & Wu, 2009), we created tasks that were meaningful to children (rather than the traditional backward digit or tone counting tasks) to keep children motivated and focused on the interference task. The two tasks that were the most appreciated and successfully completed by the children in the pilot test were retained for the experiment. In the first (“comparison task”), the children heard two names of animals or objects and were instructed to verbally respond by repeating the name of the largest one (for example: “butterfly and cat”). The task was composed of 180 different comparisons (in order to cover the whole duration of the mirror tracing task). The second task (“questions task”) consisted in answering questions whose answer should be quite obvious for young children (for example: “What is your favorite animal?” or “Who brings the presents at Christmas?”). The items were recorded by a female speaker and were read at a normal rate. Each interference task was presented with a one-second constant interstimulus interval in order to prevent self-paced allocation of attentional resources between the main task and the interference tasks (Rohrer & Paschler, 2003). In total, the task was made up of 164 questions. The percentage of answers (i.e., the number of answers given divided by the number of items presented, multiplied by 100) was recorded for the two first and two last trials of the mirror-tracing task.

**Procedure**

Children were tested individually in a quiet part of their school. In each age group, the children were randomly assigned to one of the two learning conditions. In the *single-task* condition, they performed only the mirror tracing task. In the *dual-task* condition, they performed the mirror tracing task while concurrently performing an auditory task. The interference task was introduced during the first two learning trials (i.e., trials 1–2 of the first session) and the last two learning trials (i.e., trials 19–20 of the second session) of the mirror tracing task. Half of the dual-task participants were administered the questions task during the first two trials, and the comparison task during the last two trials, and conversely for the other half.

**Results**

**Auditory interference task**

As a first step, we wanted to ensure that differences in the primary task did not result from differential performance on the interference task. Therefore, the percentage of answers given by participants in the dual-task condition on the interference task during the first and last learning phases was analyzed through an Age Group (7 vs. 10 years) × Learning Phase (first vs. last) ANOVA.

During the first learning phase (trials 1-2), although 10-year-olds tended to give more responses during the interference task than 7-year-olds (M = 72.78% vs. M = 64.83%), the effect of age was not significant, *F*(1, 35) = 2.49, *p =*.12, ηp2=.07. The main effect of learning phase was significant, *F* (1, 35) = 119.27, *p <*.001, ηp2=.77: the children gave more responses at the end than at the beginning of the procedural learning task (for 7-year-olds: 97.75%; for 10-year-olds: 99.49%). No significant interaction was revealed, *F* (1, 35) = 0.88, *p =*.35, ηp2=.02.

We conducted regression analyses in order to test whether differences in the allocation of attentional resources to the secondary task were associated with the performance differences found on the mirror tracing task. The results showed no relationship between performance on the auditory interference task and performance on the mirror tracing task (7yrs: β = .28, *p =*.60, R² = .02; 10 years: β = 1.78, *p =*.20, R² = .10).

**Dual-task interference effects on procedural learning**

For the measures of performance on the mirror tracing task, square transforms for errors and log transforms for completion time were used in order to obtain a normal distribution. Figs 1A and 1B show the untransformed completion times and number of errors for the first and last learning phases of the mirror tracing task for each age group as a function of learning condition (single vs. dual task).

To determine whether performance in the dual task during the first learning phase differed as a function of age, we conducted two ANOVAs with age group (7 and 10 years old) and learning condition (single- and dual-task) as between subjects factors on (a) completion time (mean tracing time on the two first trials), and (b) errors (mean number of errors on the two first trials). The first, on completion time, revealed a significant main effect of age group, *F*(1,71) = 20.51, *p* < .001, ηp2=.22, no main effect of learning condition, F(1,71) = 2.76, *p*  = .10, ηp2=.04, and importantly, a significant Age Group × Learning Condition interaction, *F*(1,71) = 4.01, *p =*.049, ηp2=.05. Planned comparisons confirmed our prediction, indicating that 10-year-olds were influenced by learning condition (*p* = .01) whereas 7-year-olds were not (*p* = .81).

The results of the second analysis, on the number of errors, were similar ; there was a significant main effect of age group, *F*(1, 71) = 10.07, *p* = .002, ηp2=.12, no main effect of learning condition, F(1,71) = 0.55, *p*  = .46, ηp2=.008., and a significant Age Group × Learning Condition interaction, *F*(1, 71) = 6.85, *p =*.01, ηp2=.09. Planned comparisons again indicated that 10-year-olds were affected by learning condition (*p = .02*), whereas 7-year-olds were not (*p = .19*).

Consistent with these results, analyses of simple effects revealed an effect of age in the single-task condition (for completion time: *F*(1, 71) = 21.62, *p* < .001, ηp2 = .23, and errors rate: *F*(1, 71) = 16.99, *p* < .001, ηp2 = .19), but not the dual-task condition (completion time, *F*(1, 71) = 3.15, *p* = .08, ηp2 = .04, and errors (F(1, 71) = 0.15, p = .70, ηp2 = .002). Our results thus confirmed our second hypothesis that, during the first learning phase, 7-year-old children performed similarly as 10-year-old children in the dual-task condition (when implicit processes prevail), whereas performance of the 7-year-old children was poorer than that of the 10-year-olds in the single-task condition.

Finally, we compared the effect of the interference task when it was reintroduced at the end of the learning process (after 16 practice trials without interference, when performance was at ceiling). During trials 19–20, the ANOVA revealed neither a significant effect of learning condition (time: *F*(1, 71) = 0.22, *p =*.64, ηp2=.003; errors: *F*(1, 71) = 0.82, *p =*.37, ηp2=.01) nor a significant Age Group × Learning Condition interaction (time: *F*(1, 71) =1.52, *p =*.22, ηp2=.02; errors: *F*(1, 71) = 0.11, *p =*.74, ηp2=.001). This result confirms that the skill was automatized in the two age groups.

**A**

**B**

*Figure 1.* Mean completion times (A) and mean number of errors (B) for the first and last learning phases of the mirror tracing task by age group (7 and 10 years old) as a function of learning condition (single- vs. dual-task). Error bars represent standard errors.

**Discussion**

The results of this study support our hypotheses. First, the impact of the dual task differed between age groups during the first learning phase: 10-year-old children were more affected by the interference task than 7-year-old children. Specifically, the performance of 10-year-old children was degraded by the imposition of the interference task, whereas no difference between learning conditions was revealed in the 7-year-old group. Importantly, these results cannot be attributed to ceiling or floor effects (both error rates and completion time could have been either higher or lower than was found). Second, our results showed that, in the dual-task condition during the first learning phase, when implicit memory processes prevailed, the procedural performance of 10-year-old children in terms of both time and errors was close to that of 7-year-olds; on the other hand, in the single-task condition in which explicit processes predominated in older children, 7-year-old children performed significantly worse than 10-year-old children. This is concordant with developmental studies which argue that explicit processes mature with age (e.g., Waber et al., 2007), whereas implicit learning processes are invariant with age (e.g., Meulemans et al., 1998). Finally, the dual-task condition did not affect performance at the end of the learning process, indicating that, at this stage, both age groups were able to perform the mirror tracing task automatically.

Overall, our results demonstrate that the mechanisms underlying performance during the first step of procedural learning differ between age groups: the performance of the 10-year-old children is congruent with a top-down conception of procedural learning (i.e., the first stage is sustained by explicit mechanisms; e.g., Anderson, 1982), whereas the results obtained in the 7-year-old group support the bottom-up conception (i.e., performance in the first learning stages are sustained by implicit mechanisms; e.g., Sun et al., 2001).

As suggested by Willingham (1998), a motor task can be performed in either a conscious or an unconscious mode. In the unconscious mode, subjects are aware of the goal to be reached, but not of how to perform the task. In the conscious mode, which requires more attention, subjects are conscious of the perceptuomotor demands of the task (e.g., the transformation of the vision/motor relation) and use strategic processes which lead to more accurate performance. The results obtained by our 10-year-old group in the single-task condition are consistent with this view: they used explicit processes to perform the task, allowing them to achieve better performance levels than the 10-year-old children in the dual-task condition. On the other hand, the 7-year-old children’s performance seems mainly supported by the unconscious mode, as attested by their lesser sensitivity to the interference task. As the literature on the development of executive processes throughout childhood suggests (e.g., Brocki & Bohlin, 2004), strategy formation may be more difficult for young children. Moreover, we recently showed that age-related differences observed in performance on a procedural learning task were at least partly due to the differential involvement of inhibition abilities, which are less developed in 7-year-olds than in 10-year-olds (Lejeune et al., 2013).

To rule out the possibility that the absence of a learning condition effect in 7-year-olds could be linked to characteristics of the interference task itself, and to how subjects performed this secondary task (for instance, the children could have focused on the main task at the expense of the interference task), we verified that all children performed the auditory interference task equally: no significant age difference was found on the auditory task. Regression analyses showed that differences between children in the allocation of attentional resources to the secondary task did not account for the performance differences reported in the mirror tracing task. Therefore, the lack of difference between the single- and dual-task conditions in younger children cannot be attributed to a lack of cognitive investment in the interference task. On the other hand, the impact of the secondary task on 10-year-olds’ performance proves that the interference task used in this study was complex enough to occupy cognitive resources.

In the two age groups, children gave significantly more responses at the end than at the beginning of the procedural learning task. This indicates that performing the mirror tracing task required less cognitive resources at the end than at the beginning of the learning process. As suggested by several authors (e.g., Sun, Slusarz, & Terry, 2005), procedural performance is not supported exclusively by implicit rather than explicit mechanisms, but rather that, in most situations, both types of learning act in parallel and the relative contribution of each varies according to, for instance, task parameters (i.e., the introduction of an interfering task forces the transition to more implicit learning; Sun et al., 2005), and (as suggested by our findings) the learner’s cognitive abilities. Indeed, our study indicates that there are differences in the amount of effortful processing that 7- and 10-year-olds engage at the beginning of the learning process. For instance, while our 7-year-old children used mainly implicit mechanisms to accomplish the task, explicit processes, and more generally attentional processes, could also intervene early in performance; this could explain the differences obtained in the auditory task at the beginning and end of the mirror tracing task.

Finally, despite the age differences in level of performance, no difference in the rate of acquisition (trials 3 to 18) was revealed between the age groups, which supports the results that we obtained in a previous study (Lejeune et al., 2013), and reinforces the idea that the involvement of explicit mechanisms is not a necessary condition for skill learning to occur. Although further research will be needed to confirm this conclusion (for instance, studies in which the interference task is applied throughout the learning process), our results suggest that the role of explicit mechanisms in this type of task may be not to sustain the learning process itself, but instead to allow the subject to better control his/her performance (for instance, by limiting errors) on a task that has not yet been automatized. This idea is in agreement with previous reports on perceptuomotor adaptation tasks in adults (e.g., Krakauer & Mazzoni, 2001).

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