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Preschoolers can be instructed to use proactive control

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Highlights

- We induced preschoolers to use proactive control in the AX-CPT through simple instructions, with no change to the task structure.
- Preschoolers having received proactive instructions were as proactive as older children.
- The same effect was not observed with simple practice on the task.
- The developmental shift from reactive to proactive control is primarily a change in preferential selection of the control mechanism.

Abstract

Developmental improvement of cognitive control is partly grounded in a transition from reactive control (waiting for a critical stimulus to occur) to proactive control (preparing control in advance based on active maintenance of contextual information). Whereas older children and adults spontaneously use proactive control, children younger than 5-6 years of age usually rely on the less effortful and less effective reactive control in cognitive tasks. Prior studies hint that preschoolers may not be *incapable* of using proactive control, but that they usually fail to *spontaneously engage* in proactive control. As a way to better understand the reasons for the qualitative change in control mechanisms across development, the present study explored whether preschoolers can be induced to use proactive control through explicit instructions. A sample of 77 preschoolers and school-aged children completed two sessions of the AX-CPT paradigm: a baseline session, and one session either with proactive instructions, or without specific instructions. Results showed that asking children to use proactive control – but not simple practice – led preschoolers to demonstrate a clearly proactive pattern. Preschoolers in the proactive condition demonstrated no difference in degree of proactivity compared to older children. This confirms that the development of proactive control is less about acquiring a radically new ability and more about prioritizing a different way of tackling the task. Four hypotheses to explain the developmental shift from spontaneous selection of reactive to proactive control are proposed.

Keywords

Dual mechanisms of control (DMC); Proactive control; Cognitive control; Strategy training; Cognitive development

The ability for cognitive control (goal-directed regulation of thoughts and behaviors) dramatically improves during childhood (Diamond, 2013; Garon et al., 2008), which contributes to developmental milestones such as readiness for school entry (Blair, 2002; for other examples, see Hughes, 1998; Kochanska et al., 1997). This developmental improvement appears to be partly driven by a qualitative shift from a less effective to a more effective mechanism of cognitive control (Brahmbhatt et al., 2010; Chatham et al., 2009; Chevalier et al., 2015; Gonthier et al., 2019; Munakata et al., 2012). Namely, children would progressively transition from using reactive control (passively waiting for the critical stimulus that requires control to appear) to using proactive control (actively preparing a response in an anticipatory fashion, based on contextual information).

Proactive control is both more costly, requiring active maintenance of contextual information before a probe appears, and more effective in situations where contextual information provides reliable cues (see Braver et al., 2007; Braver, 2012). These features make the preferential adoption of proactive control a plausible pivotal point of cognitive development. The idea that younger children do not use proactive control also fits well with other aspects of explicit control limitations in early childhood (for a detailed discussion, see Gonthier, Ambrosi, & Blaye, 2021), including a difficulty in processing contextual cues (Chevalier, 2015a), in actively maintaining information in working memory (Gonthier et al., 2019; Troller-Renfree et al., 2020), and in implementing actions based on internal goal representations (Diamond & Taylor, 1996; Marcovitch et al., 2007; Towse et al., 2007; Zelazo et al., 2003).

Prior studies have described a clear pattern of increasing proactive control up until late adolescence (Brahmbhatt et al., 2010; Chatham et al., 2009; Chevalier, 2015a; Chevalier et al., 2015, 2018; Chevalier & Blaye, 2016; Lorscheid & Reimer, 2008, 2010; Lucenet & Blaye, 2014; Munakata et al., 2012; Polizzotto et al., 2018; Troller-Renfree et al., 2020). In a

study using the classic AX-CPT paradigm (see next section), the age of transition between reactive and proactive control was situated around 5.5 years of age (Gonthier et al., 2019; see also Blackwell & Munakata, 2014; Chevalier, 2015a; Lucenet & Blaye, 2014). This transition seems relatively clear-cut: younger children seem to rely more or less exclusively on reactive control (Barker & Munakata, 2015; Blackwell & Munakata, 2014; Chevalier, 2015; Gonthier et al., 2019; Munakata et al., 2012), whereas most older children appear to use proactive control (e.g. Lucenet & Blaye, 2014). Overall, this pattern of results suggests a consistent view of children progressively acquiring the ability to use the more effective mechanism of proactive control, due perhaps to increasing ability to maintain the relevant contextual information in working memory (Gonthier et al., 2019; Troller-Renfree et al., 2020) or to other improvements in cue processing or goal implementation (for a discussion, see Gonthier et al., 2021; for other examples, see Chevalier et al., 2018; Chevalier & Blaye, 2016).

There are however at least three reasons to doubt that children below 5 years of age are actually incapable of using proactive control, and to suspect that reality may be somewhat more complex. First, although low working memory capacity is often cited as the main mechanistic reason why younger children do not use proactive control (e.g. Gonthier et al., 2019; Lucenet & Blaye, 2014; Munakata et al., 2012), using proactive control in common cognitive control tasks usually requires active maintenance of a single piece of goal-related information. While preschoolers do demonstrate a low working memory capacity, it is certainly sufficient to hold a single item active (for a discussion, see Gonthier et al., 2019). Second, even preschoolers who predominantly use reactive control appear capable of using proactive control in certain paradigms when the situation is modified to encourage the use of this mechanism, for example when contextual information required to respond is only presented before cue onset (Chevalier et al., 2015; for other examples, see Elke & Wiebe, 2017; Freier et al., 2021; Hadley et al., 2020; Jin et al., 2020; Lucenet & Blaye, 2019; see

also Yanaoka et al., 2021). Third, preschoolers do demonstrate a form of proactive control when it is triggered implicitly, that is, based on statistical regularities extracted from the task implicitly and without awareness (Gonthier et al., 2021).

All these arguments suggest that preschoolers should also be capable of explicitly using proactive control in a task; in other words, that the observed developmental transition may be less about gaining the *ability to use* proactive control and more about starting to *spontaneously engage* in proactive control (Gonthier et al., 2019). The latter possibility would have very different implications for the cognitive skills of preschoolers, and would lead to a different line of research regarding the determinants of this transition: the developmental shift in cognitive control would have to be investigated in terms of how a control mechanism is selected to tackle the task, more than in terms of an increasing ability to implement control of behavior.

A straightforward solution to tell these two possibilities apart is to try to instruct preschoolers to use proactive control. If explicit instructions are sufficient to create a proactive pattern of behavior in preschoolers, then their use of reactive control is related to the selection of a control mechanism rather than an intrinsic inability to use proactive control. Testing this solution requires both a task that can disambiguate which control mechanism the child is using, and a way to induce the use of proactive control: these are described in the next section.

The AX-CPT and the Induction of Proactive Control

The AX-CPT is the paradigm most frequently employed to assess variability in the use of proactive and reactive control (Braver, 2012; Braver et al., 2007), and has served in the majority of studies claiming that young children do not use proactive control. The task requires subjects to respond to pairs of stimuli (usually letters when working with adults, and images with children): a trial includes a first stimulus (the cue), followed by a delay, then by

a second stimulus (the probe). Subjects are instructed to give a target response to the probe if it is an X, but only if it was preceded by the cue A (AX trials). There are four trial types in the task: AX trials, AY trials (an A cue followed by a probe other than X), BX trials (a cue other than A followed by an X probe), and BY trials (a cue other than A followed by a probe other than X).

Subjects who use proactive control can prepare a target response during the delay period when they see an A cue, due to the large proportion of AX trials in the task (usually 70% or 40%). Proactive control leads to high performance on BX trials where the B cue makes it possible to safely prepare a non-target response. However, using proactive control is detrimental on AY trials where the A cue leads to incorrectly preparing a target response. Conversely, subjects who use reactive control wait for the probe to appear before selecting a response: this is detrimental on BX trials, where the X probe tends to lure subjects into erroneously making a target response, but it leads to high performance on AY trials where the probe directly signals the correct answer. The use of proactive or reactive control is thus reflected in the balance of performance between AY and BX trials. Preschoolers demonstrate high AY and low BX performance, indicative of reactive control (Gonthier et al., 2019; see also Chatham et al., 2009); this is also the case for older adults (Paxton et al., 2008) and adults with specific impairments, such as schizophrenia or dementia of Alzheimer type (e.g. Barch et al., 2001; Braver et al., 2005). By contrast, children older than 5.5 years and young adults demonstrate low AY and high BX performance, indicative of proactive control. The difference is especially apparent for error rates, which are of primary interest with children in the age range of preschoolers (Gonthier et al., 2019).

A method labeled "strategy training" exists to induce the use of proactive control in the AX-CPT¹ (see Gonthier et al., 2016). The rationale is straightforward: subjects are informed or reminded that A cues are usually followed by X probes, which makes it a viable strategy to prepare their response in advance during the delay period based on the cue; they are instructed to use this method when completing the task; and they perform a series of practice trials where they are required to explicitly announce the response they prepare during the delay period. This method successfully induces participants to use proactive control, shifting from a reactive pattern (with lower BX than AY performance) to a proactive pattern (with higher BX than AY performance), with a substantially larger effect on error rates than on RTs (Gonthier et al., 2016; Paxton et al., 2006). Initially developed for use with small samples of older adults (Paxton et al., 2006; see also Braver et al., 2009) and schizophrenic patients (Edwards et al., 2010), this method also performs well with larger samples of non-clinical young adults (Gonthier et al., 2016; see also Rosales et al., 2022; although inducing proactive control in adults only reveals a substantial benefit if the task is modified to encourage use of reactive control in the first place). Strategy training of proactive control has however never been tested with children.

Rationale for the Present Study

The overarching goal of the current study was to determine whether preschoolers are capable of using proactive control when explicitly instructed to do so using this method, without any other alteration to the task. This involved three questions, in ascending order of complexity: 1) do preschoolers shift to a proactive control pattern when instructed to do so? 2) if so, is this shift towards proactive control larger than what could be obtained through

¹ Induction of proactive control has also been achieved via the use of reward or monetary incentives (e.g. Chiew & Braver, 2011, 2014; Hefer & Dreisbach, 2017) and via the induction of positive emotions (Chiew & Braver, 2011, 2014), but these methods tend to have lower effect sizes, they have been less systematically tested, and they would be more difficult to use with children.

simple practice, given that practice can sometimes increase the use of proactive control (Paxton et al., 2006)? and 3) if so, how do the results of children having received proactive instructions compare to those of older children?

To answer these questions, a group of 4- to 6-year-old children, and an older group of 7- to 9-year-old children included for comparison, completed the AX-CPT. We chose the AX-CPT due to two advantages over other tasks used in prior literature, such as cued task-switching (e.g. Chevalier et al., 2015). The first was that the behavioral pattern of results on AY and BX trials in the task explicitly indicates whether a child is using reactive or proactive control (in contrast with other paradigms where use of proactive control has to be inferred from higher performance). The other was that a well-established method was available (Gonthier et al., 2016; Paxton et al., 2006) to induce proactive control based only on instructions (in contrast with other paradigms where induction of proactive control requires altering the structure of the task, such as removing a cue when the target appears; Chevalier et al., 2015; Elke & Wiebe, 2017), allowing for a more powerful test of the hypothesis that preschoolers are capable of using proactive control without aid, based only on verbal demands.

Children performed two sessions of the task, with Session 1 serving as a baseline and Session 2 implementing the experimental manipulation. Children performed Session 2 either in a Control condition (identical to Session 1 without further instructions), or in a Proactive condition using the strategy training method to induce proactive control. The use of two between-subjects control and proactive groups made it possible to disentangle the effect of proactive instructions from a practice effect, and the use of two within-subjects sessions made it possible to test whether strategy training induced changes in cognitive control above and beyond preexisting differences between the groups. The use of two sessions also had the

important benefit of avoiding confronting preschoolers with both the (complex) task instructions for the AX-CPT and the proactive instructions at the same time.

Regarding our predictions:

- 1) We expected preschoolers in the Proactive condition to shift from a reactive pattern in Session 1, to a proactive pattern akin to older children (with more AY errors than BX errors; see Gonthier et al., 2019) in Session 2 (i.e. an effect of Session in the Proactive condition for preschoolers).
- 2) Given the recurring difficulties of preschoolers with proactive control, we expected children in the Control condition to demonstrate no major shift towards proactive control compared to children in the Proactive condition (i.e. a Session*Condition interaction for preschoolers).
- 3) Given that older children spontaneously use proactive control in the AX-CPT (Gonthier et al., 2019), the proactive instructions were expected to have less of an effect in the older age group, eliciting a smaller difference between the Control and Proactive conditions (i.e. a Session*Condition*Age interaction). The results of preschoolers in the Proactive condition were also expected to resemble the results of children in the older age group.

Method

Sample Size

The effect of proactive induction is typically large. In a similar study with older adults, Paxton et al. (2006) found an effect size of $\eta^2_p = .30$ for the shift towards proactive control after proactive induction. This effect size would require a sample of $N = 34$ to achieve .95 power (Faul et al., 2007). The effect size was even larger in a study with young adults when comparing the effect of proactive induction to a reactive condition (Gonthier et al., 2016), with $\eta^2_p = .39$ requiring a sample of $N = 24$ for .95 power. The 2019 COVID pandemic made it impossible to collect two classes per grade level, so age groups were made

to span two years (4- to 6-year-old and 7- to 9-year-old) and data collection was planned for two classes per age group (about $N = 40$ children for the 4- to 6-year-old group and 7- to 9-year-old group).

Participants

The sample comprised 81 children, including $n = 40$ children in the 4- to 6-year-old group (including 17 children in pre-kindergarten and 19 children in kindergarten; mean age = 5.30 years, $SD = 0.63$; 24 girls and 13 boys) and $n = 41$ children in the 7- to 9-year-old group (including 19 children in 2nd grade and 24 children in 3rd grade; mean age = 8.16 years, $SD = 0.64$; 20 girls and 24 boys). The slight imbalance in gender ratio across age groups had no effect on the results (there were no interactions with gender and the results remained identical when controlling for gender). All participants were native French speakers, all attended the class corresponding to their age group, and none had participated in an experiment before. Of note, an additional five children in the 4- to 6-year-old group in the Proactive condition (four children in pre-kindergarten and one child in kindergarten) were excluded in Session 2 because they failed to follow the proactive instructions².

AX-CPT Paradigm

The AX-CPT was adapted from versions used in prior studies with preschoolers (Gonthier et al., 2019; see also Lucenet & Blaye, 2014). In each trial, children viewed a fixation cross for 500 ms, the picture of an animal (the cue) for 1000 ms, an unfilled delay of 1500 ms, then a second picture of an animal (the probe) presented until a response was made. Children were required to press the green target button with their dominant index finger if the

² All five children appeared unable to say out loud the color corresponding to the most likely response during the delay between cue and probe (see the *Proactive instructions* section below), despite multiple reminders. These children completed the training and the first block of trials, then were thanked and sent back to class. They are not counted in the total sample size.

first animal was a hen (A cue) and the second animal was a cat (X probe), and to press the blue non-target button with their other index finger in all other cases. Animals used for non-AX trials were a bear, a cow, a dog, a donkey, a giraffe, a lion, a monkey, a mouse, a rabbit, a sheep, a snake, and a turtle. The response had to be made within a subject-specific deadline, computed as the child's average response time plus one standard deviation. Children received audio feedback after each trial indicating whether their response was correct, incorrect, or too slow.

Session 1 was broken down as follows: a first phase controlled for the child's knowledge of animal names by having them name each animal picture in turn. The instructions for the AX-CPT were given, and the child completed 8 demonstration trials, accompanied with experimenter instructions, and which could be repeated if necessary. The child then completed a short training of 16 trials before proceeding to the main task. There were three blocks of 30 trials (18 AX, 4 AY, 4 BX, and 4 BY; i.e., 60% AX, 13.3% AY, 13.3% BX, and 13.3% BY). Every block started with an additional AX trial which was discarded prior to data analysis. Trials were presented in the same pseudorandom order for all children; there were never more than 3 consecutive trials requiring the same response, and sequences of 1 AX trial, 2 AX trials, and 3 AX trials occurred three times each. Children were reminded of the task goals between each block and received a sticker after each block. Session 2 was largely identical to Session 1: children were reminded of the task instructions, then completed 24 training trials, followed by three blocks of 30 trials.

Proactive Instructions

The task itself was identical for children in the two conditions, but for children in the Proactive condition, the instructions differed as follows. An additional step was added at the very end of Session 1: the experimenter pointed out that there had been many hen-cat trials, which made it helpful to prepare a green-button response when the first animal was a hen;

and conversely, that a blue-button response could be prepared whenever the first animal was not a hen. This served to prime the proactive instructions in Session 2.

At the beginning of Session 2, children in the Proactive condition were reminded that it was helpful to prepare a green-button response when the first animal was a hen and a blue-button response otherwise. They then completed the 24 training trials as follows (see Gonthier et al., 2016): for the first 8 trials, the experimenter said out loud the most likely response ("green" or "blue") during the delay between the cue and probe animals, while the child completed the task. For the next 8 trials, the child said out loud the most likely response, while the experimenter completed the task. For the last 8 trials, the child said out loud the most likely response while completing the task. Children then completed the three task blocks; for the first task block, they were asked to continue saying the most likely response out loud during the delay between cue and probe. For the other two task blocks, they were encouraged to keep anticipating their response in advance, and they were told that they were no longer forced to say the likely response out loud (although they were allowed to continue doing so)³. Children in the Control condition completed the same 24 training trials and the same three task blocks in Session 2, but without further instructions.

Procedure

Informed written consent was obtained from the children's parents prior to the experiment and all children also gave verbal assent to participate. The approval of an ethics committee was not required under local regulations.

All children in a class were invited to complete the experiment. Experimental conditions were counterbalanced within each class (the Control and Proactive conditions

³ The three task blocks of Session 2 were analyzed together to maximize the number of trials. Restricting the analysis to blocks 2 and 3 (which were strictly identical in the two conditions) gave very similar results: in particular, the same effects of interest were significant for the effect of training, the interaction between session and experimental condition, and the interaction with age group.

were systematically alternated, so as to control for possible effects of the order in which children were invited for testing). Children were tested individually in a quiet room at their school. Receiving instructions and completing the AX-CPT took approximately 30 minutes per session. The second session took place on the same week whenever possible (median inter-session delay = 3 days).

Data Analysis

Trials where the child failed to respond within the deadline were excluded from analysis. Mean RTs were computed from correct trials only. As usual in this type of study, the analysis of raw RTs provided little information, presumably due to large between-subjects variations of speed (Gonthier et al., 2019); these data are available in Table 1 and in the supplemental materials but they are not discussed further. Instead, we focus here on standardized RTs (which account for age-related differences of speed: Faust et al., 1999; see also Braver et al., 2005; Gonthier et al., 2019; Lorscheid & Reimer, 2010; Paxton et al., 2006, 2008), as computed separately for each trial type (AX, AY, BX, BY) based on each participant's grand average and standard deviation.

To summarize the use of proactive control, we used the proactive behavioral index (PBI), which directly reflects the balance of performance between AY and BX trial (higher PBI values indicate more use of proactive control). The PBI was computed as $(AY - BX) / (AY + BX)$, separately for error rates and RTs (Braver et al., 2009). To account for trials where the error rate was zero, log-linear correction was applied to all error rates prior to computing the PBI (for details, see Gonthier et al., 2016; Hautus, 1995). Lastly, a composite PBI was computed by averaging the PBI for errors and the PBI for RTs after standardization (applied across the two sessions so that values of the composite PBI could be compared between sessions).

Results

Two children with 100% error rates on one trial type were excluded from the dataset (one child in the 4-6-year-old group with 100% BX errors and one child in the 7-9-year-old group with 100% AY errors). The data were also screened for outliers using Cook's distance prior to each analysis, but no data point had sufficient influence to substantially change the conclusions and all other subjects were kept. The final sample size was thus $N = 79$ (with $n = 18$ children for the 4- to 6-year-old group in the control condition, $n = 18$ children for the 4- to 6-year-old group in the proactive condition, $n = 21$ children for the 7- to 9-year-old group in the control condition, and $n = 22$ children for the 7- to 9-year-old group in the proactive condition). Descriptive statistics are displayed in Table 1. The data file can be accessed via the Open Science Framework platform at <https://osf.io/7nbtik/>.

For simplicity, the analyses were broken down in three sections matching our three research questions: 1) The first set of analyses investigated the effect of the proactive instructions, by comparing Session 1 and Session 2 in the Proactive condition of the 4- to 6-year-old group. 2) The second set tested whether the effect of the instructions in the 4- to 6-year-old group went above and beyond practice in the control condition, by testing the interaction with experimental condition. 3) The final set of analyses tested whether the effect of the proactive instructions was stronger in the 4- to 6-year-old group than in the 7- to 9-year-old group by testing the interaction between experimental condition and age group⁴.

The complete results are displayed in Figure 1 (for error rates), Figure 2 (for standardized response times) and Figure 3 (for the PBI measures). Only effects directly

⁴ Note that this is equivalent to testing the three-way interaction between session, condition and age group, and then decomposing this interaction in subsequent analyses; here the results are presented in reverse order for clarity and consistency with the hypotheses.

relevant to our hypotheses are presented here; omnibus ANOVA tables are available as supplemental material at <https://osf.io/7nbtik/>.

1) Test of the Proactive Shift in Preschoolers in the Proactive Condition

For 4- to 6-year-old children in the Proactive condition, error rates showed a significant two-way interaction between Session (Session 1 vs. Session 2) and Trial type (AX, AY, BX, BY⁵), $F(3, 51) = 6.45$, $p < .001$, $\eta^2_p = .28$, reflecting a shift towards proactive control. These results are displayed in Figure 1 (top right panel). In line with our hypothesis, planned comparisons indicated that children had significantly lower AY error rates than BX error rates in Session 1, indicating the use of reactive control, $F(1, 17) = 4.54$, $p = .048$, $\eta^2_p = .21$; this pattern changed to significantly higher AY error rates than BX error rates in Session 2, indicating use of proactive control after the proactive instructions, $F(1, 17) = 8.79$, $p = .007$, $\eta^2_p = .34$.

For standardized RTs, the analysis again showed a significant two-way interaction between Session and Trial type, $F(3, 51) = 7.52$, $p < .001$, $\eta^2_p = .31$, reflecting a shift towards more proactive control. These results are displayed in Figure 2 (top right panel). As in prior work with adults (Gonthier et al., 2016), children were slower on AY trials than BX trials in both Session 1, $F(1, 17) = 11.23$, $p = .004$, $\eta^2_p = .40$, and Session 2, $F(1, 17) = 63.55$, $p < .001$, $\eta^2_p = .79$; but a contrast analysis restricted to AY and BX trials confirmed that children were disproportionately slower on AY trials than BX trials in Session 2, when compared to Session 1, $F(1, 17) = 13.61$, $p = .002$, $\eta^2_p = .44$, indicating a shift towards proactive control.

⁵ Although AX and BY trials are not theoretically relevant to our hypotheses, we retain them in the omnibus ANOVAs in line with AX-CPT literature. Follow-up planned comparisons are performed for the theoretically-relevant AY and BX trials only. Restricting the omnibus analyses to AY and BX trials led to the same conclusions.

Analyzing the PBI measures confirmed that preschoolers in the Proactive condition demonstrated an increase in proactive control between Session 1 and Session 2, as reflected in a substantially increased composite PBI, $F(1, 17) = 28.86, p < .001, \eta^2_p = .60$. These results are displayed in Figure 3 (right panel). This increase was also manifest separately in both the PBI computed on errors, $F(1, 17) = 15.42, p = .001, \eta^2_p = .48$, and the PBI computed on RTs, $F(1, 17) = 9.97, p = .006, \eta^2_p = .37$.

2) Comparison between the Proactive and Control Conditions in Preschoolers

The second set of analyses tested whether the proactive instructions had an effect beyond simple practice in the group of preschoolers. A preliminary analysis showed that children in the Control condition and in the Proactive condition had similar performance at baseline: there were no significant differences for performance on any of the trial types in Session 1 (all $ps > .15$). Critically, there was no difference at baseline for any of the PBI measures (all $ps > .25$) and no interaction between condition and trial type for error rates or RTs (both $ps > .45$).

For error rates, a 2 (Condition: Control vs. Proactive) x 2 (Session: First session vs. Second session) x 2 (Trial type: AX, AY, BX, BY) mixed-design ANOVA indicated a significant three-way interaction between Condition, Session and Trial type, $F(3, 102) = 3.30, p = .023, \eta^2_p = .09$, reflecting the fact that the balance between trial types changed from Session 1 to Session 2 to different extents in the Control condition and in the Proactive condition. This interaction is represented in Figure 1 (top panels). Contrary to the Proactive condition, children in the Control condition had significantly lower AY error rates than BX error rates in both Session 1 and Session 2, both $ps < .05$, indicating a reactive pattern in both sessions, and they did not show a proactive shift at all, $F(1, 17) = 0.00, p = .955, \eta^2_p = .00$.

A similar pattern appeared for standardized RTs, with a significant three-way interaction between Condition, Session and Trial type, $F(3, 102) = 3.81, p = .012, \eta^2_p = .10$ indicating a greater shift towards proactive control in the Proactive condition than in the Control condition (see Figure 2, top panels). Again, planned comparisons indicated that children in the Control condition showed no significant proactive shift from Session 1 to Session 2, $F(1, 17) = 0.57, p = .460, \eta^2_p = .03$.

These results were generally reflected in the analyses for the PBI measures. The two-way interaction between Condition and Session was significant for the PBI composite, $F(1, 34) = 9.89, p = .003, \eta^2_p = .23$, and for the PBI computed on errors, $F(1, 34) = 9.59, p = .004, \eta^2_p = .22$, confirming that children in the Proactive condition shifted towards proactive control above and beyond an effect of practice. Again, there was no difference between Session 1 and Session 2 for children in the Control condition, for either the composite PBI, $F(1, 17) = 0.24, p = .632, \eta^2_p = .01$, or the PBI computed on errors, $F(1, 17) = 0.16, p = .697, \eta^2_p = .01$. For the PBI computed on RTs, the two-way interaction between Condition and Session was not significant, $F(1, 34) = 1.69, p = .202, \eta^2_p = .05$, but the results were descriptively in the expected direction (see Figure 3): contrary to the Proactive condition, there was no significant shift towards proactive control in the Control condition, $F(1, 17) = 1.50, p = .237, \eta^2_p = .08$.

3) Comparison between Age Groups

The final set of analyses tested whether the difference across sessions between the Control and Proactive conditions varied as a function of age group. For error rates, a 2 (Age group: 4- to 6-year-old vs. 7- to 9-year-old) x 2 (Session: First session vs Second session) x 2 (Condition: Control vs. Proactive) x 4 (Trial Type: AX, AY, BX, BY) mixed-design ANOVA found the predicted four-way interaction between the four variables, $F(1, 75) = 4.03,$

$p = .008$, $\eta^2_p = .05$. This interaction is represented in Figure 1. This four-way interaction was driven by the fact that there was no significant three-way interaction between Condition, Session and Trial type in the 7- to 9-year-old group, $F(3, 123) = 0.80$, $p = .494$, $\eta^2_p = .02$, contrary to preschoolers. In other words, the balance of performance between AY and BX trials changed as a function of the combination of Condition and Session, but only in the younger age group.

Of secondary interest, the 7- to 9-year-old age group did show a significant two-way interaction between Session and Trial Type, $F(3, 123) = 13.27$, $p < .001$, $\eta^2_p = .24$. This reflected the fact that older children, while already using proactive control in Session 1, demonstrated a further shift towards proactive control between Session 1 and Session 2, to similar extents in the two experimental conditions (see Figure 1, bottom panels). This shift towards proactive control through simple practice has been described in the adult literature (Paxton et al., 2006), and it is noteworthy that it only existed in the 7- to 9-year-old group: by contrast, the pattern of error rates remained remarkably constant across sessions in the Control condition for the 4- to 6-year-old group (see Figure 1, top left panel).

For standardized RTs, the four-way interaction between Age group, Condition, Session and Trial type was not significant, $F(1, 75) = 1.00$, $p = .396$, $\eta^2_p = .01$. The RT data were thus less sensitive to the induction than error rates, as in prior work with older adults (Paxton et al., 2006). However, the results were again descriptively in the expected direction: contrary to preschoolers in the Proactive condition, the 7- to 9-year-old group did not show significant evidence of a proactive shift, with neither an interaction between Session and Trial Type, $F(3, 123) = 1.14$, $p = .334$, $\eta^2_p = .03$, nor a three-way interaction with Condition, $F(3, 123) = 0.98$, $p = .405$, $\eta^2_p = .02$. These results are displayed in Figure 2.

Lastly, the composite PBI showed the expected three-way interaction between Age group, Condition and Session, $F(1, 75) = 8.25$, $p = .005$, $\eta^2_p = .10$, indicating that the effect of

proactive instructions across the two experimental sessions was different for the two age groups, in line with our hypotheses. This three-way interaction is represented in Figure 3. Contrary to preschoolers, there was no two-way interaction between Condition and Session in the 7- to 9-year-old group, $F(1, 41) = 0.96$, $p = .332$, $\eta^2_p = .02$, indicating that the proactive instructions had no substantial effect beyond practice in older children. The results for the PBI computed on error rates closely matched those of the composite PBI. There was a significant three-way interaction between Age group, Condition and Session, $F(1, 75) = 10.08$, $p = .002$, $\eta^2_p = .12$, as represented in Figure 3, and there was no two-way interaction between Condition and Session in the 7- to 9-year-old group, $F(1, 41) = 1.38$, $p = .247$, $\eta^2_p = .03$. For the PBI computed on RTs, the three-way interaction between Age group, Condition and Session was not significant, $F(1, 75) = 1.49$, $p = .227$, $\eta^2_p = .02$, confirming that the interaction observed for the PBI composite was mostly driven by a change in error rates.

Given these results, we conducted a series of analyses to test whether there remained differences in the degree of proactivity of 4- to 6-year-old children after receiving proactive instructions, and 7- to 9-year-old children. These analyses used planned contrasts restricted to the second session. Since we intended to test for a lack of difference between groups, we complemented the results with Bayesian analyses to quantify evidence in favor of the null hypothesis (Morey & Rouder, 2018). The results indicated that the PBI in the Proactive condition of the 4- to 6-year-old group did not differ from the average of the two conditions of the 7- to 9-year-old group, indicating that they had comparable levels of proactive control. This was true for the composite PBI, with substantial evidence in favor of the null, $F(1, 75) = 1.37$, $p = .246$, $\eta^2_p = .02$, $BF_{10} = 0.32$. There was also no difference for the PBI computed on errors; $F(1, 75) = 1.87$, $p = .176$, $\eta^2_p = .02$, $BF_{10} = 0.43$; and the PBI computed on RTs; $F(1, 75) = 0.19$, $p = .668$, $\eta^2_p = .00$, $BF_{10} = 0.29$.

By contrast, the Control condition of the 4- to 6-year-old group was significantly below the average of the Proactive condition of the 4- to 6-year-old group and the two conditions of the 7- to 9-year-old group, for the composite PBI, $F(1, 75) = 43.11$, $p < .001$, $\eta^2_p = .36$, $BF_{10} = 1885219$; the PBI computed on errors; $F(1, 75) = 38.69$, $p < .001$, $\eta^2_p = .34$, $BF_{10} = 453996$; and the PBI computed on RTs; $F(1, 75) = 13.64$, $p < .001$, $\eta^2_p = .15$, $BF_{10} = 75.37$. In other words, the proactive instructions were sufficient to raise proactive control in the 4- to 6-year-old group to levels comparable to the older age group in session 2 (see Figure 3), but this was not true at all for the control condition.

Table 1

Descriptive statistics for all measures

Age group	Measure	Control condition		Proactive condition	
		Session 1	Session 2	Session 1	Session 2
4- to 6-year-old	AX ER	.07 (.08)	.06 (.07)	.04 (.04)	.03 (.03)
	AY ER	.10 (.11)	.11 (.14)	.05 (.09)	.21 (.22)
	BX ER	.24 (.23)	.25 (.22)	.14 (.14)	.08 (.11)
	BY ER	.06 (.09)	.08 (.11)	.05 (.06)	.05 (.08)
	AX RT	1239 (399)	1294 (478)	1065 (323)	808 (294)
	AY RT	1531 (443)	1550 (528)	1383 (488)	1067 (359)
	BX RT	1471 (538)	1365 (551)	1199 (517)	774 (374)
	BY RT	1348 (508)	1414 (616)	1162 (496)	797 (316)
	AX RTz	-0.15 (0.12)	-0.12 (0.11)	-0.15 (0.16)	-0.06 (0.12)
	AY RTz	0.60 (0.56)	0.46 (0.44)	0.65 (0.38)	0.99 (0.46)
	BX RTz	0.29 (0.53)	0.01 (0.36)	0.07 (0.49)	-0.25 (0.41)
	BY RTz	0.01 (0.38)	0.11 (0.40)	0.04 (0.50)	-0.10 (0.35)
	PBI ER	-0.20 (0.44)	-0.25 (0.45)	-0.25 (0.44)	0.30 (0.32)
	PBI RT	0.04 (0.12)	0.08 (0.11)	0.09 (0.12)	0.18 (0.09)
	PBI com.	-0.72 (0.79)	-0.63 (0.76)	-0.58 (0.64)	0.32 (0.53)
7- to 9-year-old	AX ER	.04 (.05)	.03 (.03)	.03 (.03)	.02 (.03)
	AY ER	.12 (.20)	.29 (.21)	.13 (.16)	.22 (.22)
	BX ER	.07 (.10)	.05 (.10)	.07 (.14)	.05 (.12)
	BY ER	.01 (.03)	.02 (.04)	.01 (.02)	.01 (.03)
	AX RT	577 (146)	516 (147)	598 (131)	503 (110)
	AY RT	696 (144)	641 (198)	778 (209)	651 (153)
	BX RT	518 (215)	437 (183)	566 (231)	447 (135)
	BY RT	496 (184)	471 (185)	567 (219)	458 (130)
	AX RTz	0.06 (0.17)	0.07 (0.13)	-0.01 (0.17)	0.00 (0.16)
	AY RTz	0.93 (0.49)	0.93 (0.44)	1.00 (0.49)	1.11 (0.60)
	BX RTz	-0.44 (0.54)	-0.60 (0.44)	-0.32 (0.55)	-0.37 (0.50)
	BY RTz	-0.54 (0.36)	-0.36 (0.37)	-0.31 (0.55)	-0.33 (0.34)
	PBI ER	0.10 (0.51)	0.49 (0.39)	0.20 (0.44)	0.41 (0.38)
	PBI RT	0.17 (0.12)	0.20 (0.11)	0.18 (0.12)	0.19 (0.12)
	PBI com.	0.08 (0.85)	0.59 (0.59)	0.22 (0.74)	0.46 (0.58)

Note. Means with standard deviations in parentheses. ER = Error rate; RT = Response time; RTz = Standardized response time; PBI = Proactive behavioral index; PBI com. = composite PBI.

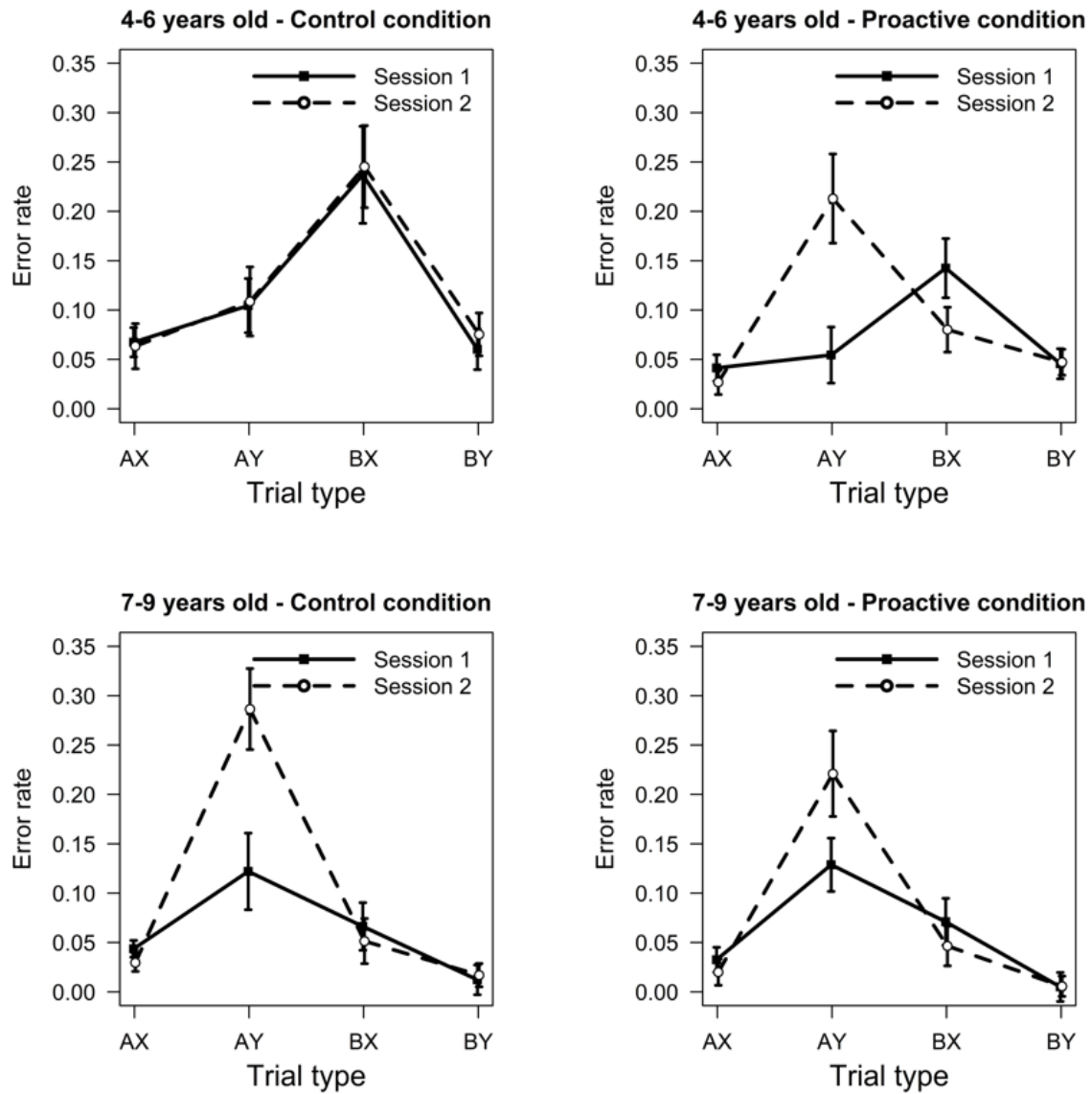


Figure 1. Error rates as a function of age group and experimental condition. Error bars represent within-subject standard errors of the mean (Morey, 2008).

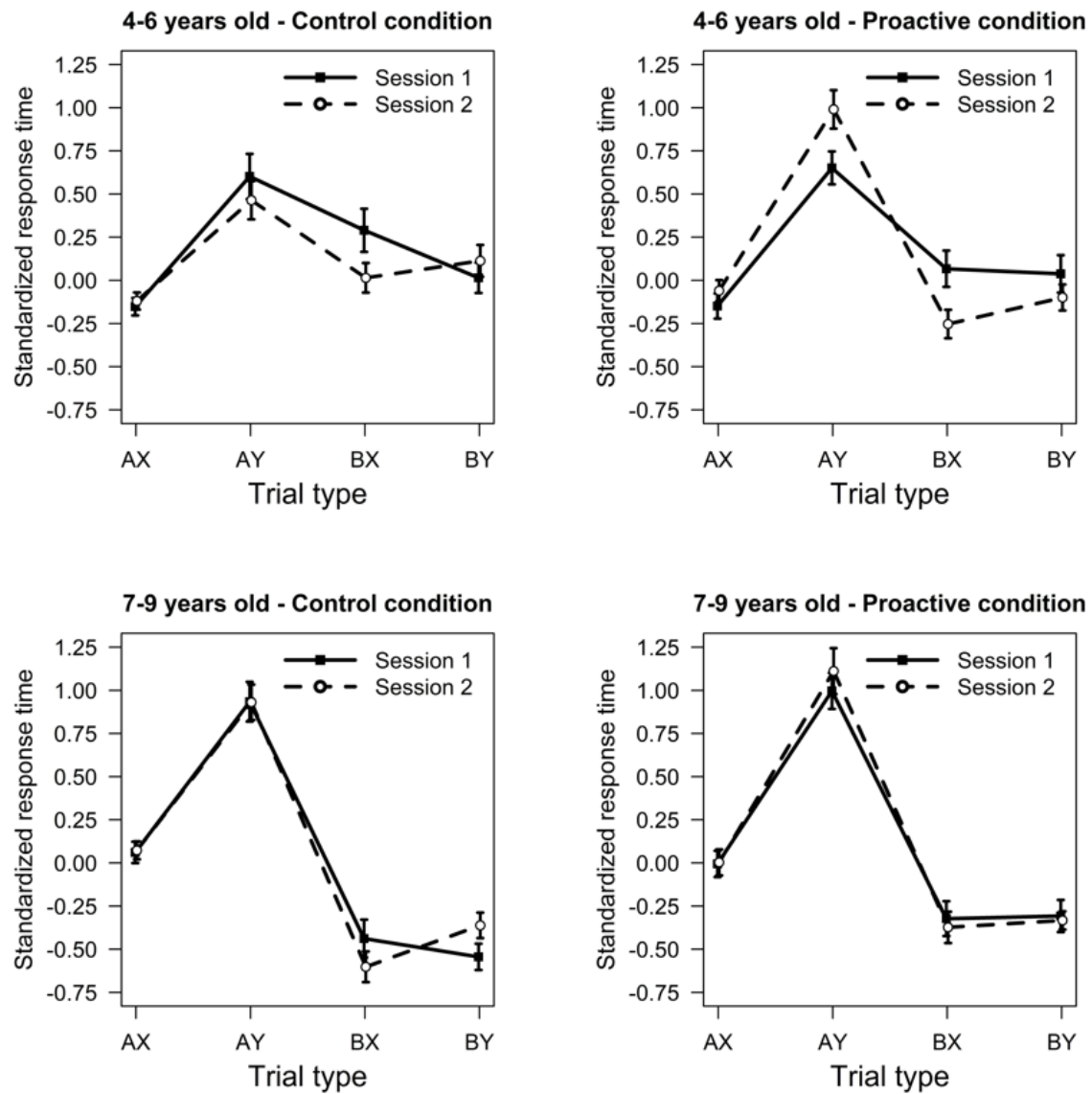


Figure 2. Standardized response times as a function of age group and experimental condition. Error bars represent within-subject standard errors of the mean (Morey, 2008).

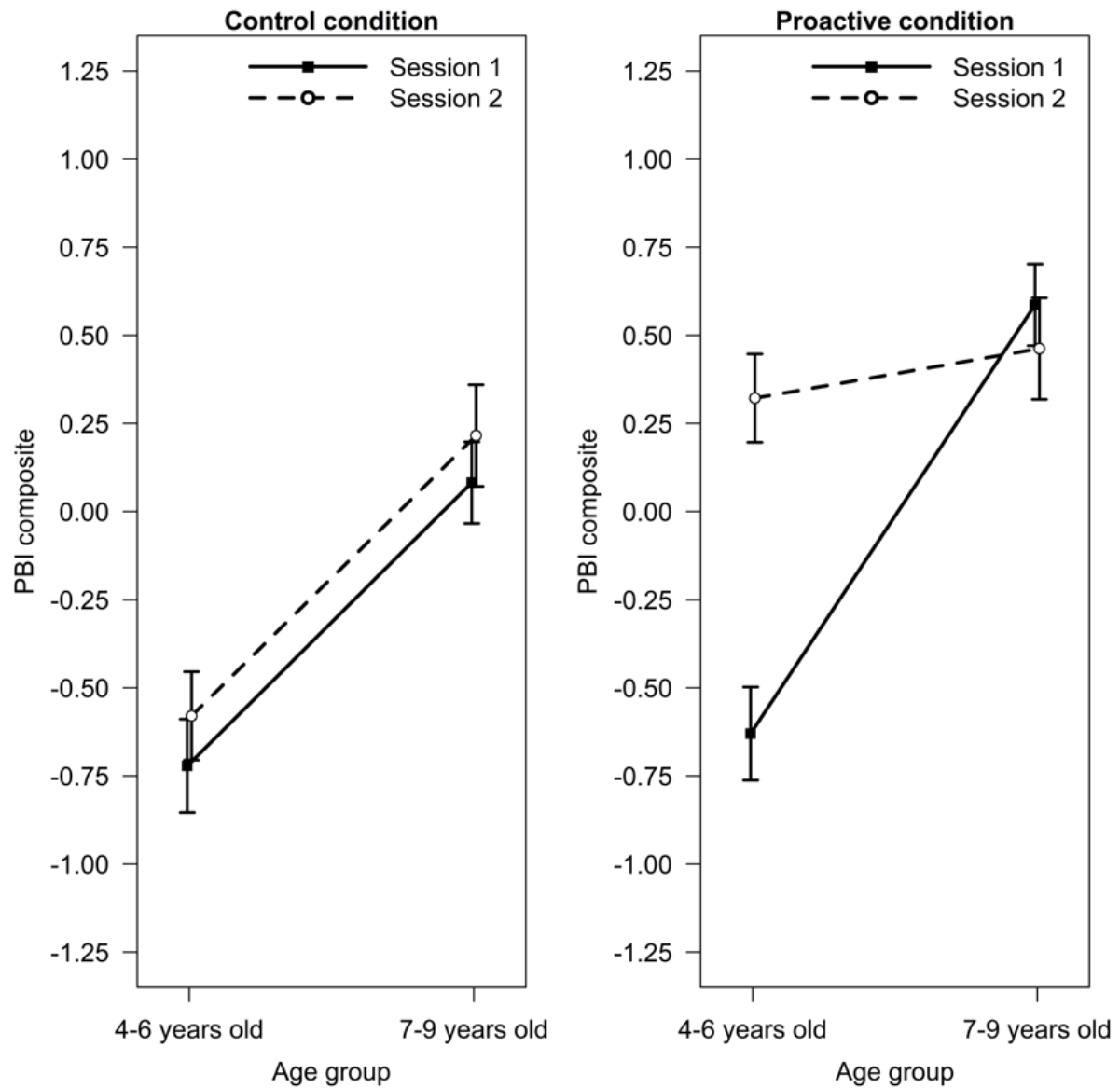


Figure 3. Proactive behavioral indices as a function of age group and experimental condition. Error bars represent within-subject standard errors of the mean (Morey, 2008).

Discussion

The objective of this study was to determine whether preschoolers are capable of voluntarily engaging proactive control in a classic control task, the AX-CPT, when given explicit instructions to do so but without any changes to the task structure itself. The results revealed that children in the Proactive condition did switch from reactive control to predominant use of proactive control, as reflected in higher BX than AY performance after proactive instructions. This pattern was only observed for preschoolers who received proactive instructions: preschoolers who completed an identical task in a Control condition without specific instructions did not turn to proactive control through simple practice, and older children, already using proactive control, did not substantially benefit from training. In sum, the results showed that preschoolers, despite not using proactive control spontaneously, are indeed capable of doing so upon demand – to the extent that instructing children to use proactive control without any other change to the task is sufficient to induce the use of proactive control.

Critically, instructing preschoolers to use proactive control also had a strong enough effect on their pattern of performance that there were no longer any significant differences between 4- to 6-year-old and 7- to 9-year-old children in their use of proactive control, as reflected in the PBI measure (Figure 3). Moreover, this increase in proactive control was not accompanied by a drop in overall correct rates, contrary to a prior study with task-switching (Chevalier et al., 2015): although 4- to 6-year-old children in the proactive condition remained slower, their error rates in session 2 in fact became very close to those of older children⁶ (see Figure 3). This may be due to the fact that implementing proactive control is

⁶ Contrast analyses for Session 2 showed that error rates in the Proactive condition of the 4-6 years old group did not significantly differ from the average of the two conditions of the 7-9 years old group for AX trials ($p =$

more straightforward in the AX-CPT (where the upcoming response can be anticipated) than in cued task-switching (where only the upcoming *task* can be anticipated), or to the fact that proactive control was more guided in our study (children were explained how to implement proactive control through explicit instructions, as opposed to the manipulation encouraging proactive control by removing the cue during target presentation in Chevalier et al., 2015). Whatever the reason, these results strongly support the notion that the developmental shift from reactive to proactive control is best understood as a difference in terms of which control mechanism children engage spontaneously, rather than a core inability of the younger children to use proactive control.

Overall, these results converge with prior studies to confirm that there is no such thing as a "proactive developmental stage" that would be inaccessible to younger children. Past research had managed to provide evidence for proactive control in preschoolers when modifying the task to provide scaffolding: through making reactive control more difficult (Chevalier et al., 2015), making it possible to engage proactive control unconsciously based on implicit triggers related to statistical regularities (Gonthier et al., 2021), repeatedly asking children to monitor and estimate their performance (Hadley et al., 2020), providing rewards (Jin et al., 2020), forcing children to convert cues into explicit task goals (Lucenet & Blaye, 2019), or allowing children to choose task-related stimuli (Freier et al., 2021). Most of these paradigms obtained only small effects at the behavioral level, and none were directly designed to disentangle reactive and proactive control, contrary to the AX-CPT – which means they could observe some extent of advance preparation in preschoolers, but they were not equipped to test the use of proactive over reactive control. The present study is thus the first evidence of preschoolers demonstrating explicit proactive control in the princeps

.855), AY trials ($p = .477$), BX trials ($p = .429$), or BY trials ($p = .072$). By contrast, error rates in the Control condition of the 4-6 years old group significantly differed from the three other conditions for all of AX trials ($p = .001$), AY trials ($p = .019$), BX trials ($p < .001$), and BY trials ($p = .007$).

paradigm designed to measure the use of this mechanism, based on simple instructions but without any alteration to the task structure itself, and with a very large effect size for proactive instructions ($\eta^2_p = .60$ for the composite PBI measure).

Why don't Preschoolers Spontaneously Engage in Proactive Control?

If proactive control is generally more effective, and if preschoolers can use this mechanism when instructed to do so, why then do they fail to use proactive control spontaneously? Another way to ask this question is to ponder why the method used here to induce proactive control (Paxton et al., 2006) was effective with preschoolers: which component(s) of the strategy training successfully affected a dimension of behavior that is not spontaneously present in preschoolers and bars them from spontaneously using proactive control? Unfortunately, this induction method was designed to confound several manipulations in order to maximize the chances of observing proactive control: subjects receive explanations about the structure of the task, they are made aware of the benefit of using proactive control, they are told how to use proactive control, and they are explicitly asked to use it. This means the manipulation is not well-suited to testing fine-grained hypotheses about what is required to induce proactive control (or about the reason why participants do not use it in the first place).

The present results are however helpful to narrow down the possible sources of the lack of proactive control in preschoolers. Based on the structure of the proactive instructions (and prior literature: for related discussions, see Chevalier, 2015b; Gonthier et al., 2021), we believe the most feasible explanations are the following. Note that these possibilities are not mutually exclusive and could all contribute to the lack of proactive control in preschoolers:

Hypothesis 1. Perhaps preschoolers fail to identify the contingency between cue and probe (the high likelihood of an X-probe after an A-cue), which would prevent them from identifying the possibility of preparing a response in advance. In this view, the important

component of the proactive instructions would be the overt explanation that the A-cue is often followed by an X-probe. This explanation is possible, but appears unlikely given that preschoolers are capable of implicitly learning subtle statistical regularities and using them to regulate cognitive control engagement (Gonthier et al., 2021; Gonthier & Blaye, 2021).

Hypothesis 2. Perhaps preschoolers fail to realize that a response can be prepared in advance, which is explicitly explained in the proactive instructions. This view amounts to claiming that there is a difference in the repertoire of strategies known by preschoolers (e.g. Lemaire & Siegler, 1995), and to saying that preschoolers have not yet discovered or acquired the method of anticipating the most likely response in advance based on contextual information (see Yanaoka et al., 2021, for a conceptually similar hypothesis). In this view, the important component of the proactive instructions would be the explanation of how to use proactive control, and perhaps the associated practice trials. This too appears unlikely, given prior literature showing that preschoolers can implement proactive control when the task is modified in a way that encourages preparing a response in advance, but without any explicit instruction to that effect, such as removing a cue when the target appears (Chevalier et al., 2015; Elke & Wiebe, 2017), encouraging performance monitoring (Hadley et al., 2020) or proposing rewards (Jin et al., 2020). All these manipulations seem more liable to encourage mapping proactive control to a new context or strengthening the probability of using proactive control (Siegler, 1996), than to lead to the discovery of proactive control from scratch over a few dozens of trials.

Hypothesis 3. Perhaps preschoolers fail to realize that preparing a response in advance is beneficial, or equivalently, misjudge the relative effectiveness of preparing a response in advance versus not doing so (because they think that they are doing well enough through reactive control, or because they think preparing a response is not an effective approach). In other words, preschoolers would know the method of preparing a response in advance, but

they would fail to use it due to low metacognitive skills (e.g. Chevalier et al., 2015; Chevalier & Blaye, 2016; see also Hadley et al., 2020, for the idea that encouraging performance monitoring promotes proactive control). This idea is also conceptually related to the notion of utilization deficiency (see Clerc et al., 2014; Clerc & Miller, 2013). In this view, the important component of the proactive instructions would be the explanation of the benefit of using proactive control, provided at the very end of Session 1 and repeated at the beginning of Session 2.

Hypothesis 4. Perhaps preschoolers refrain from using proactive control because it feels too subjectively costly or too resource-demanding. Proactive control is usually described as taxing in terms of cognitive resources (Braver et al., 2007), and young children are no less reluctant than older children to engage in cognitive effort (Chevalier, 2018). Given that young children have low working memory capacity, given that proactive control requires active maintenance of cue-related information in working memory (Braver et al., 2007), and given that the development of proactive control is related to the development of working memory capacity (Gonthier et al., 2019; Troller-Renfree et al., 2020), it is possible that the required maintenance in working memory is too costly for preschoolers to engage spontaneously, even if they are objectively capable of doing so (Gonthier et al., 2019). This is compatible with the finding that making reactive control more difficult increases the use of proactive control in preschoolers (Chevalier et al., 2015). In this view, the most important aspect of the proactive instructions would be the explicit request that the child use proactive control.

Limitations and Perspectives for Future Research

The current study was interested in the effects of training proactive control, as a tool to determine whether the developmental shift from reactive to proactive control is primarily driven by a shift in how a mechanism is selected to tackle the task. It was not, however, about

the possibility of training proactive control in a way that could persist over time and transfer to other tasks. This would not seem to be a particularly desirable objective to us: proactive control comes with associated costs, both in terms of cognitive effort or resources, and in terms of vulnerability to violations of expectations and rigidity in the face of changing conditions (Blackwell & Munakata, 2014; Braver et al., 2007). As such, it is not necessarily the optimal strategy for young children who may have less resources and less ability to recover from disruption. Since the overwhelming majority of young adults appear to naturally use proactive control, there is little point in trying to artificially provoke a developmental transition before it occurs naturally.

For this reason, the study was not designed to test whether the effect of instructions transferred to another task or persisted over time, only whether instructions were enough to provoke the use of proactive control. In other words, the current work constituted a mechanistic study rather than an efficacy or effectiveness study of training (Green et al., 2019). Preschoolers who received the proactive instructions demonstrated a proactive pattern of behavior until the end of the task, but it is unknown whether the effects of the instructions would have carried over to a different session performed days or months after this one, or even to a different task performed on the same day. We do not have particular expectations on this point about transfer of the strategy training to a different task: the proactive manipulation used for the AX-CPT is very task-specific, and strategic mechanisms do not necessarily transfer well to other tasks anyway, especially in children (Clerc et al., 2014; Clerc & Miller, 2013).

On the other hand, testing whether the effects of instructions persist over time could be an interesting window into understanding why preschoolers do not spontaneously use proactive control in the first place. If the reason is that they have not yet discovered this mechanism (*Hypothesis 2*), then preschoolers having received the proactive instructions

should retain a proactive pattern over subsequent sessions, even if these sessions are performed without any further instructions. If the reason is that proactive control is too subjectively costly for preschoolers to engage without an explicit experimental demand (*Hypothesis 4*), the effects of proactive instructions should disappear in subsequent sessions in the absence of repeated instructions. Testing this would be useful, although it would be a costly protocol requiring three or more testing sessions – all using the AX-CPT paradigm, which is not an entertaining task for children.

Other hypotheses about the determinants of preferential selection of reactive control in preschoolers could be tested by decomposing the major components of the strategy training method, i.e. the proactive instructions. For example, if preschoolers fail to realize the benefits of using proactive control (*Hypothesis 3*), but understand how to use proactive control in the task and are willing to engage the required effort, then proactive instructions including only the metacognitive component (explaining that proactive control is useful, as done at the end of Session 1) should be sufficient to induce proactive control. In this sense, the hypotheses outlined in the previous section can provide a roadmap for future research on this topic.

An interesting result in the present study, although not directly related to our purposes, is the complete absence of a shift towards proactive control with simple practice in the group of preschoolers (see in particular Figure 1, top left panel). This contrasts with findings in the group of 7- to 9-year-old children; with findings in older adults, who spontaneously use reactive control but who have a tendency to revert to proactive control with practice in the AX-CPT (Paxton et al., 2006); and with findings obtained in preschoolers with a cued task-switching paradigm, where children demonstrated increased cue-related pupil dilation in the window before a probe appeared, after simple practice with a task (Yanaoka et al., 2021).

The discrepancy with the practice-related shift towards proactive control observed for the AX-CPT in older children and in older adults (Paxton et al., 2006) may point to a meaningful specificity of preschoolers, possibly related to their lack of spontaneous use of proactive control. The absence of spontaneous orientation towards proactive control with practice in preschoolers is reconcilable with all four hypotheses outlined in the previous section: more practice may not be helpful enough for preschoolers to identify the contingency between cue and probe, to understand the possibility of preparing a response in advance, to acknowledge the benefit of using proactive control, or to decide to invest enough cognitive effort to engage this mechanism.

The discrepancy with the results obtained with preschoolers in cued task-switching (Yanaoka et al., 2021) is less straightforward. It may be due to the low magnitude of the observed effects: the change in pupil dilatation observed by Yanaoka and colleagues was not associated with large behavioral effects (as put by the authors, the results did not show "for certain" that preschoolers in the control group actually underwent a change from reactive to proactive control). Another possibility would be that the less complex structure of the cued task-switching paradigm, when compared to the AX-CPT, made it easier for children in the control condition to spontaneously discover proactive control. If this is the case, the lack of spontaneous proactive control might be primarily driven by the absence of this strategy in children's repertoire (*Hypothesis 2*). Future studies may then be interested in exploring practice-related shifts in behavior in various paradigms as a window into the roots of the developmental transition towards proactive control.

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