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Many studies have highlighted the huge developmental increase in the effectiveness of cognitive control: children get progressively more adept at regulating their behavior to produce a goal-directed response (Diamond, 2013; Garon et al., 2008), and these improvements continue until adolescence. Conversely, preschoolers are notoriously poor at identifying task goals, maintaining task goals and implementing task goals (Chevalier, 2015b; Karbach & Kray, 2007; Munakata et al., 2012; Zelazo et al., 2003), using these task goals to prepare a response in advance (Gonthier et al., 2019), refraining from producing a response (Garon et al., 2008), and so on. A considerable literature thus converges to paint the picture of young children as essentially "control-impaired", with a tendency to respond in an automatic rather than controlled manner. Is the ability of preschoolers for cognitive control really so low?

In contrast with this bleak picture, a few studies have begun to suggest that when the situation provides scaffolding, even very young children are capable of implementing relatively effective forms of control to regulate their behavior. One example is when the situation strongly encourages anticipation, by making it difficult or impossible to respond without considering goal-related information in advance: in this case, 4-5-year-olds appear capable of using a proactive form of control (Chevalier et al., 2015; Elke & Wiebe, 2017) that does not usually appear before later development (Gonthier et al., 2019). Another example is control triggered by implicit events within a task, which also appears to allow for flexible regulation of behavior in young children. The purpose of this study was to investigate the extent of these implicit control capabilities in preschoolers.

Implicit Cognitive Control and its Development

Adult literature has distinguished between cognitive control triggered from explicit cues (explicit cognitive control), which is performed intentionally and usually with awareness; and cognitive control triggered from information extracted implicitly from the task (implicit cognitive control; see Blais, 2010; Bugg et al., 2015; Kunde et al., 2012; van Gaal et al., 2012). Explicit control operates when subjects regulate their behavior based on an explicit cue or expectation, and with the explicit intent of doing so. By contrast, implicit control operates when an event in the task (such as encountering conflictual information, or making an error) implicitly prompts the subject to increase cognitive control so as to strengthen goal-directed behavior, without being aware of it[1].

Implicit cognitive control is a relatively recent notion, and is still an emerging field of research in the adult literature (see Braem et al., 2019; Bugg & Crump, 2012; Kunde et al., 2012; van Gaal et al., 2012; Schmidt, 2016). Critically, the idea of implicit control has major consequences for developmental research. Several studies have suggested that when control is triggered implicitly, preschoolers are capable of surprisingly flexible forms of behavior regulation. In fact, we have argued that this constitutes evidence in favor of a functional dissociation between explicit and implicit control (Gonthier et al., 2021), an ongoing debate in the adult literature (Bugg et al., 2015; Bugg & Crump, 2012; Cohen-Shikora et al., 2018; Kunde et al., 2012).

Two major examples of such implicit cognitive control being functional in preschoolers are post-error slowing (selectively slowing on the trial immediately following an

[1] The idea of "implicit cognitive control" thus refers both to the act of control itself when it is triggered based on an implicit event, and to the flexible modulation of control that this represents. The two are confounded in experimental paradigms: the operation of implicit cognitive control manifests as selectively enhanced performance in a condition that implicitly signals the need for control, when compared to a condition that does not.

error; see Dutilh et al., 2012), and congruency sequence effects (reduced interference on the trial immediately following an incongruent trial in a conflict task). These two effects can reflect very local implementations of cognitive control, as implicitly triggered by experience on the immediately preceding trial. Both post-error slowing (Gupta et al., 2009; McDermott et al., 2007; Wiersema et al., 2007) and congruency sequence effects (Ambrosi et al., 2016; Iani et al., 2014; Larson et al., 2012; Wilk & Morton, 2012) appear to be functional as early as 4 or 5 years old.

The present study was centered on a third type of implicit control: proportion congruency (PC) effects (for reviews, see Braem et al., 2019; Bugg & Crump, 2012). PC effects are observed in conflict tasks, such as the Stroop task or the flanker task, where stimuli have both a relevant dimension and an irrelevant dimension. For example, in the Stroop task, subjects are required to name the color in which a color name is written (relevant but non-predominant dimension) while refraining to read the word itself (irrelevant but dominant dimension). Incongruency between the relevant and irrelevant dimensions creates conflict; cognitive control is required to orient behavior towards the goal-relevant dimension in the face of this conflict. PC effects refer to the finding that conflict is reduced when most trials in a condition are incongruent. This decreased conflict is taken to reflect the operation of implicit cognitive control: subjects are thought to selectively heighten cognitive control (reduce the weight of the irrelevant dimension during processing), when it is most required by the situation. Contrary to post-error slowing and congruency sequence effects, PC effects occur at a timescale much larger than the immediately preceding trial: they require the subject to implicitly learn the likelihood of conflict in a particular condition over multiple trials, then to tailor cognitive control engagement to this particular condition.

The two most studied types of PC effects are the list-wide PC effect (LWPC), where conflict in a task block is reduced when most trials in the block are incongruent; and the item-specific PC effect (ISPC), where conflict for a particular stimulus (as indexed by the relevant dimension, e.g. the ink color in the Stroop task) is reduced when most occurrences of this stimulus are incongruent trials. In a prior study, we have observed both types of effects in preschoolers (Gonthier et al., 2021). This study used flanker tasks and Stroop tasks, and employed designs aiming to decrease the role of mechanisms other than cognitive control, such as contingency learning. A series of five experiments showed that LWPC and ISPC effects both exist in 5-6-year-olds, despite children being generally unaware of the PC manipulation, and that they are of similar or higher magnitude than in 9-10-year-olds. These results confirm that young children are capable of both implicitly learning conflict likelihood, and regulating cognitive control implementation on a block-to-block or trial-to-trial basis (for conceptually similar results, see Marcovitch et al., 2007, 2010; for studies in older children, see Surrey et al., 2019; Wilk and Morton, 2012).

However, the adult literature has also found a third type of PC effect, which is arguably more fine-grained than LWPC and ISPC effects: the context-specific PC effect (CSPC). This effect has never been studied in young children (for a study with preadolescents, see Surrey et al., 2019), which constitutes the focus of the present study.

The Context-Specific Proportion Congruency Effect

The CSPC effect refers to the finding that conflict is reduced when most stimuli presented in a particular context are incongruent (Crump et al., 2006; for discussions, see Braem et al., 2019; Bugg & Crump, 2012; Cosman & Vecera, 2013). In this case, "context" means a dimension of the stimulus display that has no relation to the conflict task at all - in other words, an aspect of the stimulus that is neither the irrelevant-but-predominant dimension, nor the relevant-but-less-dominant dimension. For example, one of the first demonstrations of the CSPC effect was obtained with font type in a color-word Stroop task: subjects appeared capable of reducing interference when color names presented in a particular font were mostly incongruent (Bugg et al., 2008). In other words, subjects are capable of detecting that certain fonts, a perceptual cue completely unrelated to the task at hand, are more often associated with incongruent trials; of learning this regularity for the various fonts within a task block; and of adjusting their cognitive control settings accordingly. Importantly, the CSPC effect is not a conscious regulation on the part of the subjects (Panadero et al., 2015): they are not typically aware of the contextual manipulation (Crump et al., 2006, 2010; King et al., 2012), and informing them does not seem to affect the CSPC effect (Crump et al., 2008).

Apart from fonts (Bugg et al., 2008), most studies on the CSPC effect have manipulated context based on spatial location, so that stimuli presented in a certain spatial location are mostly incongruent or mostly congruent (Corballis & Gratton, 2003; Crump & Milliken, 2009; Crump et al., 2006, 2008; Fischer et al., 2014; Gottschalk & Fischer, 2016; King et al., 2012; Wendt et al., 2008). The CSPC effect is also found when context is manipulated through the color of stimuli (Heinemann et al., 2009; Lehle & Hübner, 2008), or their shape (Crump et al., 2006, 2008), or even by the delay that precedes the presentation of a stimulus (Wendt & Kiesel, 2011), indicating that this is a very general phenomenon.

As noted by Kunde et al. (2012, p. 13), "Adaptations to context-specific conflict frequency are striking because they suggest a very high flexibility and speed of cognitive control operations that affect response". The CSPC effect indeed requires subjects to regulate their behavior so as to decrease the conflict elicited by a stimulus, on the basis of a contextual cue that by definition can only be detected *after* the stimulus has been presented. But the CSPC effect most critically differs from LWPC and ISPC effects in that cognitive control is modulated based on a stimulus dimension that has no bearing to the task at hand, and that subjects are not particularly encouraged to process when performing the task. In the example of the font manipulation in the Stroop task (Bugg et al., 2008), subjects are never informed that there are multiple fonts and that these can signal the proportion congruency of the corresponding words, and they have no particular incentive to even notice that multiple fonts are used. By contrast, the LWPC effect is indexed by the overall proportion of congruent trials encountered by the subject throughout the task, and the ISPC effect is indexed by the relevant dimension of stimuli to which subjects are supposed to respond: in both cases, the PC signal is intrinsically embedded in a meaningful aspect of the task.

An alternative account of the CSPC effect would be that subjects do not actually regulate cognitive control implementation based on the frequency of conflict in a given context, but that they learn complex associations between the most frequent response required by a specific stimuli in a specific location (see Bugg et al., 2020; Crump & Milliken, 2009; Crump et al., 2006, 2017; Hutcheon & Spieler, 2017). In other words, interference could be reduced for stimuli presented in a mostly incongruent context (e.g. location), not because subjects flexibly adjust their control settings to decrease the weight of the irrelevant dimension when stimuli are presented in this context, but because subjects learn which response is most frequently associated with each of the stimuli presented in this particular context.

This alternative account has been used to argue against the idea of implicit cognitive control: if the CSPC effect were based on associative learning, it would not reflect implict adjustment of cognitive control settings (Schmidt, 2016; Schmidt & Lemercier, 2019; Schmidt et al., 2014). Several experiments have tested this alternative hypothesis. Although some have failed to find a CSPC effect independent of associative learning (Crump et al., 2017; Hutcheon & Spieler, 2017), others have concluded that this type of learning is not sufficient to account for the CSPC effect (Crump & Milliken, 2009; Crump et al., 2017; King et al., 2012). Associative learning does seem to inflate the CSPC effect (Crump et al., 2017; see also Schmidt, 2016; Schmidt & Lemercier, 2019), but the effect also exists for frequency-unbiased stimuli and for novel stimuli, indicating that it actually reflects the operation of cognitive control.

The CSPC effect thus appears to represent a highly subtle modulation of cognitive control, one that requires implicit learning of the conflict likelihood for a contextual dimension of stimuli that is unrelated to the task, then on-the-fly regulation of cognitive control settings when a stimulus is presented depending on its context. Unsurprisingly, the CSPC effect can be elusive even in adults (Crump et al., 2008, 2017; Hutcheon & Spieler, 2017; Lehle & Hübner, 2008; Wendt & Kiesel, 2011). It is of limited magnitude (it is typically observable on response times, with a reduction of conflict in the order of 15ms to 30ms), and it is more easily observed when the contextual cue is a salient dimension, such as stimulus location (Crump et al., 2008).

Critically, the CSPC effect has never been investigated in young children. One study found a CSPC effect in preadolescents (9-12-year-olds) using a size congruity task, and concluded that the effect was of similar magnitude to adults (Surrey et al., 2019); but this does not tell us whether the effect would be found in much younger children who usually struggle with cognitive control (Chevalier, 2015b; Garon et al., 2008; Gonthier et al., 2019; Karbach & Kray, 2007; Munakata et al., 2012; Zelazo et al., 2003). Our prior study has found LWPC and ISPC effects in preschoolers (Gonthier et al., 2021), suggesting that the basic mechanisms for this type of implicit control - implicit learning of conflict likelihood and dynamic modulation of control within a task - are indeed in place, but it remains to be tested whether young children can also demonstrate the more subtle CSPC.

There are three major reasons to study the CSPC effect in preschoolers. First, it would complete the triptych of PC effects by showing that young children demonstrate all of LWPC, ISPC, and CSPC effects, and behave similarly to adults in this respect. Second, and given that the CSPC effect is not always observed even in adults, finding a CSPC effect in preschoolers would go a long way in providing evidence that young children can implement surprisingly fine-grained modulation of cognitive control when supported by the situation, even when this modulation is based on a stimulus dimension that is completely irrelevant to the task. Third, and relatedly, finding a CSPC effect in preschoolers - who have well-known difficulties with explicit cognitive control - would also contribute additional evidence that implicit and explicit cognitive control can be functionally distinct forms of control (Gonthier et al., 2021; see also Bugg et al., 2015; Bugg & Crump, 2012; Cohen-Shikora et al., 2018; Kunde et al., 2012).

Rationale for the Present Study

The main goal of this study was to test whether preschoolers are capable of demonstrating fine-grained implicit cognitive control, in the form of a CSPC effect. Given our prior results with the LWPC and ISPC effects (Gonthier et al., 2021), we expected preschoolers to demonstrate a CSPC effect, providing support both for early cognitive control skills when the task provides implicit rather than explicit triggers, and for a functional dissociation between implicit and explicit cognitive control. This question was explored in two experiments.

Experiment 1 aimed to test whether a CSPC effect could be observed in preschoolers, and whether this effect would replicate over different types of contextual manipulations. We thus tested the CSPC effect in a group of 5-6 year-old children. To ensure the generalizability of our findings, we tested both a CSPC effect based on location (Corballis & Gratton, 2003; Crump & Milliken, 2009; Crump et al., 2006, 2008; King et al., 2012; Wendt et al., 2008) and a CSPC effect based on the shape and color of stimuli (Crump et al., 2006, 2008; Heinemann et al., 2009; Lehle & Hübner, 2008). Investigating two types of CSPC effects in preschoolers imposed several constraints on the task: we needed a conflict task, where stimulus location on screen was irrelevant and did not conflict with the response, which allowed for multiple types of stimuli, and which did not require reading. We elected to adapt the child-friendly version of the arrows flanker task, where left and right arrows are represented by left and right-facing fish (Rueda et al., 2004; for other examples, see Blakey & Carroll, 2015; Stolte et al., 2019). For half the children, context was indexed based on the type of fish (with two possible types of fish being differenciated by both their color and their shape; see Figure 1), and for the other half, context was indexed based on stimulus location (above or below fixation). The design and procedure were adapted from our prior study with LWPC and ISPC effects (Gonthier et al., 2021).

A secondary objective of Experiment 1 was to investigate the developmental trajectory of the CSPC effect. To this end, the experiment also included a group of 9-10-year-olds as a point of reference (see Surrey et al., 2019). Given that the CSPC effect is supposed to reflect the operation of cognitive control and given that cognitive control usually improves with age, the magnitude of the effect could in theory be expected to increase with age. On the other hand, if the mechanisms driving context-specific learning of conflict regularity and the corresponding adjustments of control are already well in place in preschoolers, the magnitude of the CSPC effect could be expected to remain constant, or even to decrease with age. Such a decrease is often observed when an effect depends on baseline response speed: as children grow older and their response times decrease, the absolute size of a conflict effect also tends to decrease (see Gonthier et al., 2021; Smulders et al., 2018).

Experiment 2 aimed to control for the alternative account of the CSPC effect based on the idea that subjects learn complex associations between contexts, stimuli and responses (Bugg et al., 2020; Crump & Milliken, 2009; Crump et al., 2006, 2017; King et al., 2012). If this were the case, the CSPC effect would not actually reflect early skills for implicit cognitive control in preschoolers, but rather a form of low-level associative learning. One way to control for this possibility is to use a modified design including at least four stimuli, with two stimuli serving as inducer items (biased as a function of context, creating the context-specific proportion congruency manipulation) and two stimuli serving as diagnostic - items to test the CSPC effect (unbiased as a function of context). This manipulation has been tested in adults, with some experiments failing (Crump et al., 2017; Hutcheon & Spieler, 2017) and others succeeding (Crump & Milliken, 2009; Crump et al., 2017) in finding a transfer of the CSPC effect to the unbiased diagnostic items. Experiment 2 implemented this design in a four-arrows version of the flanker task used in Experiment 1 (see Diede & Bugg, 2016), including up and down fish that served as inducer items[2] and left and right fish that served as diagnostic items.

As a manipulation check to ensure that the CSPC effect was truly implicit, we also questioned the children about their awareness of the CSPC manipulation at the end of the testing session. Finding a way to frame this question for 5-6 years old children proved difficult: prior studies have asked subjects to estimate the proportion of incongruent trials in a given context (e.g. Crump et al., 2006; Crump & Logan, 2010; King et al., 2012), but understanding and answering this question can be challenging even for adults (Crump et al., 2008). We settled on the solution of asking children which context they thought was more difficult, which seemed to be the closest feasible analog to the procedure typically used with adults.

[2] An alternative solution would have been to retain only left and right directions, and use one of the two types of fish of Experiment 1 for inducer items and the other for diagnostic items; but since the two sets of items would have required the same left/right responses, this would have raised the alternative possibility of subjects learning associations between responses and stimuli in a particular location.

Experiment 1

Method

Participants

Studies on the CSPC effect in adults using conflict tasks are usually based on sample sizes between 15 and 30 participants (Bugg et al., 2008; Corballis & Gratton, 2003; King et al., 2012; Wendt et al., 2008; Wendt & Kiesel, 2011). Data collection was planned for 45 children per age group per condition. Consent was obtained for the planned number: a total sample of 180 children thus participated in this experiment. This sample comprised 90 children in kindergarten (48 females and 42 males; mean age = 5.79 years, range = 5.17 to 6.25 years) and 90 children in 4th grade (59 females and 31 males; mean age = 9.81 years, range = 9.25 to 10.33 years). The children were recruited in French public schools and had never participated in an experiment before. They were predominantly White and of average socioeconomic status, reflecting the characteristics of the local community. All participants spoke French as their first language and attended the class corresponding to their age group. Informed written consent was obtained from the children's parents, and all children also provided verbal assent to participate. All children in a class were invited to complete the experiment. Experimental conditions were counterbalanced within each class.

Materials

The flanker task is illustrated in Figure 1. The task was presented to children as helping feed fish by indicating on which side was their head; it was illustrated with pictures of underwater scenery, on a light blue background (these materials were taken from Blakey & Carroll, 2015). The protocol was programmed in E-Prime and presented on a laptop with a 15-inches screen. Children were seated 43 centimeters from the screen. Each trial began with a fixation cross (a starfish) displayed for 850 ms in the center of the screen, followed by the stimulus which remained on the screen until response. Stimuli were sets of five fish presented on screen. The set of fish spanned 8.84° of visual angle (1.6° per fish and 0.21° between each fish; based on Rueda et al., 2004). The fish were of two possible types (Blakey & Carroll, 2015), with different shapes and colors (yellow fish and blue fish; see Figure 1); the five fish composing a given stimulus were all of the same type. Stimuli were presented either in the top part of the screen (5.7° above fixation) or in the bottom part of the screen (5.7° below fixation; see Crump et al., 2006).

Fish could go in two directions (> and <). On congruent trials the central arrow matched the flanker arrows (e.g. >>>>>), whereas on incongruent trials the central arrow conflicted with the flanker arrows (e.g. >><>>). Children were instructed to press the key corresponding to the direction of the central fish (S key for a left fish, L key for a right fish), while ignoring the flanker fish. Response keys were signaled by stickers with drawings of arrows. Children had to place their index fingers on the two response keys and answer using only these two fingers.

Children were instructed to respond as quickly and accurately as possible. In order to emphasize the need for responding quickly, a threshold for the maximum allowed RT was defined on a subject-per-subject basis. This threshold was computed as (median RT + 3 * median absolute deviation), with a maximum of 3500 ms. The threshold was recalculated after each trial based on all prior trials (for the first trials, it was calculated based on RTs during training). During the task, children received an auditory feedback after each trial indicating whether their response was too slow ("tick-tock" sound), or if it was within the RT threshold, whether it was incorrect ("buzz" sound) or correct ("woohoo" sound; adapted from Rueda et al., 2004).

Design

Children were randomly assigned to one of the two experimental conditions. In the "biased type" condition, one type of fish was MC (75% congruent) and the other type of fish was MI (25% congruent); the two types of fish were presented equally often in the top and bottom locations, which means both locations were 50% congruent. Which type of fish was MC and which type was MI was counterbalanced across subjects. In the "biased location" condition, the design was identical except top and bottom locations were MC or MI and both types of fish were 50% congruent.

In total, children completed eight blocks (in the 5-6 years old group) or ten blocks (in the 9-10 years old group) of 33 trials, and the first trial of each block was excluded; in other words, children in the 5-6 years old group completed 256 critical trials and children in the 9-10 years old group completed 320 critical trials in total. The design is summarized in Table 1. The order of trials within each block was random.

Procedure

Children were tested individually in a quiet room at their school. In order to decrease the length of the procedure while still retaining enough trials, the experiment was broken down into two testing sessions which took place on the same day (one in the morning and one in the afternoon). The first session began with a familiarization phase. This included 4 trials acquainting children with how to respond to an arrow-like fish presented alone by pressing the corresponding key, 4 trials requiring them to respond to a fish accompanied by to-be-ignored flankers (2 congruent and 2 incongruent trials), a demonstration of the 3 possible feedbacks, and lastly 4 practice trials with feedbacks (2 congruent and 2 incongruent trials). Spatial locations and types of fish were counterbalanced during this phase and were all unbiased. During this familiarization phase, the experimenter had to manually proceed to the next trial, which allowed for clarification of the instructions when needed.

Children then completed 24 training trials (proceeding without experimenter input), which could be restarted if they still had difficulty grasping the instructions; this training block was also performed at the beginning of the second session to remind children of the task requirements. Training trials were 50% congruent overall and were contextually biased according to the experimental condition. Children then proceeded to the main task (with four blocks of 33 trials in a session for the 5-6 years old group and five blocks for the 9-10 years old group). There was a short break between every block and a longer break halfway through the task. The whole procedure lasted approximately 20 to 30 minutes.

At the end of the second session, in order to assess awareness of the CSPC manipulation, children were required to indicate which type of fish (in the "biased type" condition; blue fish, yellow fish or neither) or which spatial location (in the "biased location" condition; top, bottom or neither) they thought was more difficult. This question was asked with the relevant stimuli displayed on the screen as a visual support: the blue and yellow fish were presented in a central location and the top and bottom locations were illustrated with a third type of fish not used in the rest of the task.

Data Processing

Response times were analyzed for trials with a correct answer only. Trials with a RT faster than 200ms or slower than the subject-specific threshold were dropped from all analyses (on average, this removed 8.9% of trials for the 5-6 years old group and 5.8% of trials for 9-10 years old group; the maximum was 17% for a given subject). Children with a flanker effect (for either RTs or error rates) more than three standard deviations from the average of their age group were excluded from the sample, and we also excluded children with error rates of at least 50% on any trial type. Data from the two sessions were merged prior to analysis.

Results and Discussion

One child in the 5-6 years old group was excluded with an error rate above 50%, and three children in the 5-6 years old group and two in the 9-10 years old group were excluded with a flanker effect more than three standard deviations above average, yielding a final sample size of $N = 174$ ($n = 86$ in the 5-6 years old group and $n = 88$ in the 9-10 years old group). Descriptive statistics for all measures are displayed in Table 2. The data for this experiment are available at https://osf.io/nyxv8/ [*made available upon publication*].

[Insert Table 2 approximately here]

Context-Specific Proportion Congruency Effect based on Stimulus Type

The first analysis tested whether the CSPC effect existed when indexed based on stimulus type, for both RTs and error rates. Analyses were performed using a 2 (trial type: congruent vs. incongruent) x 2 (context-specific proportion congruency: MC vs. MI) x 2 (age group) mixed-design ANOVA, restricted to subjects in the "biased type" condition.

For RTs, there was the expected effect of trial type, indicating a congruency effect: RTs were slower for incongruent trials, $F(1, 83) = 292.28$, $p < .001$, $\eta^2_p = .78$. The trivial main effect of CSPC was not significant, $F(1, 83) = 0.83$, $p = .365$, $\eta^2_p = .01$. Critically, trial type interacted with CSPC, $F(1, 83) = 24.25$, $p < .001$, $\eta^2_p = .23$, indicating a CSPC effect: interference was reduced for the MI fish when compared to the MC fish. This CSPC effect is represented in Figure 2a.

There was a significant effect of age, $F(1, 83) = 164.94$, $p < .001$, $\eta^2_p = .67$, and a significant interaction between age and trial type, $F(1, 83) = 28.01$, $p < .001$, $\eta^2_p = .25$, indicating faster RTs and smaller interference in the 9-10 years old group. There was also a significant three-way interaction between trial type, CSPC and age, $F(1, 83) = 10.24$, $p = .002$, $\eta^2_p = .11$, reflecting the fact that the CSPC effect was significantly larger in the 5-6 years old group than in the 9-10 years old group. This interaction remained even when analyzing log-transformed RTs (expressing interference as a ratio between congruent and incongruent RTs, so as to take into account age differences in baseline response speed; e.g. Kliegl et al., 1994; Meiran, 1996), $F(1, 83) = 6.48$, $p = .013$, $\eta^2_p = .07$. However, analyzing the two age groups separately indicated that the CSPC effect was significant in both the 5-6 years old group (49 ms effect), $F(1, 41) = 19.17$, $p < .001$, $\eta^2_p = .32$, and the 9-10 years old group (10 ms effect), $F(1, 42) = 4.78$, $p = .034$, $\eta^2_p = .10$.

For error rates, there was an effect of trial type, $F(1, 83) = 132.52$, $p < .001$, $\eta^2_p = .61$, reflecting a congruency effect; the main effect of CSPC was not significant, $F(1, 83) = 0.15$, $p = .702$, $\eta^2_p = .00$. Trial type did not interact with CSPC, $F(1, 83) = 0.20$, $p = .659$, $\eta^2_p = .00$, showing no CSPC effect on this dependent variable. Age did not interact with any of the variables; more specifically, the three-way interaction between trial type, CSPC and age was not significant, $F(1, 83) = 1.56$, $p = .215$, $\eta^2_p = .02$. Error rates are represented in Figure 2b.

[Insert Figure 2 approximately here]

Context-Specific Proportion Congruency Effect based on Stimulus Location

The second analysis tested whether the CSPC effect existed when indexed based on stimulus location, for both RTs and error rates. Analyses were performed using a 2 (trial type: congruent vs. incongruent) x 2 (context-specific proportion congruency: MC vs. MI) x 2 (age group) mixed-design ANOVA, restricted to subjects in the "biased location" condition.

For RTs, there was the expected effect of trial type, indicating slower RTs for incongruent trials, $F(1, 87) = 246.52$, $p < .001$, $\eta^2_p = .74$. The main effect of CSPC was not significant, $F(1, 87) = 2.24$, $p = .138$, $\eta^2_p = .03$. As was the case for the "biased type" condition, trial type interacted with CSPC, $F(1, 87) = 8.23$, $p = .005$, $\eta^2_p = .09$, indicating a

CSPC effect: interference was reduced in the MI location when compared to the MC location. This CSPC effect is represented in Figure 3a.

There was a significant effect of age, $F(1, 87) = 166.01$, $p < .001$, $\eta^2_p = .66$, and a significant interaction between age and trial type, $F(1, 87) = 18.42$, $p < .001$, $\eta^2_p = .17$, indicating faster RTs and smaller interference in the 9-10 years old group. Although the CSPC effect was again descriptively larger for the younger age group, similar to the "biased type" condition, the three-way interaction between trial type, CSPC and age was not significant in this analysis, $F(1, 87) = 1.15$, $p = .287$, $\eta^2_p = .01$. Analyzing the same three-way interaction with log-transformed RTs supported this conclusion, $F(1, 87) = 0.05$, $p = .825$, $\eta^2_p = .00$. Testing the CSPC effect in the two age groups separately confirmed that it was significant in both the 5-6 years old group (28 ms effect), $F(1, 43) = 4.07$, $p = .050$, $\eta^2_p = .09$, and the 9-10 years old group (14 ms effect), $F(1, 44) = 12.35$, $p = .001$, $\eta^2_p = .22$.

For error rates, there was the expected effect of trial type, $F(1, 87) = 156.15$, $p < .001$, $\eta^2_p = .64$, and a trivial main effect of CSPC, $F(1, 87) = 6.44$, $p = .013$, $\eta^2_p = .07$. However, trial type did not interact with CSPC, $F(1, 87) = 1.71$, $p = .194$, $\eta^2_p = .02$, showing no CSPC effect on this dependent variable. Age did not interact with any of the variables; more specifically, the three-way interaction between trial type, CSPC and age was not significant, $F(1, 87) = 1.84$, $p = .179$, $\eta^2_p = .00$. Error rates are represented in Figure 3b.

[Insert Figure 3 approximately here]

Comparison Between the Effects of Stimulus Type and Location

The previous analyses showed that the CSPC effect significantly decreased with age when it was indexed by stimulus type, but not when it was indexed by stimulus location. This raised the question of whether effects were significantly different for the two manipulations; the results of prior studies suggest that this could be the case (see Crump et al., 2006, 2008).

We did not have specific hypotheses on this topic, but we performed this analysis for exploratory purposes, using a 2 (trial type: congruent vs. incongruent) x 2 (CSPC: MC vs. MI) x 2 (age group) x 2 (CSPC manipulation: type vs. location) mixed-design ANOVA.

The results for RTs showed that the three-way interaction between trial type, CSPC, and CSPC manipulation was not significant, $F(1, 170) = 0.86$, $p = .354$, $\eta^2_p = .01$, indicating that the magnitude of the CSPC effect was similar for the type and location conditions. The three-way interaction between trial type, CSPC, and age was significant, $F(1, 170) = 8.14$, $p = .005$, $\eta^2_p = .05$, reflecting significantly reduced magnitude of the CSPC effect in the 9-10 years old group when considering the two conditions simultaneously; the same three-way interaction was marginally significant when tested on log-transformed RTs, $F(1, 170) = 3.26$, $p = .073$, $\eta^2_p = .01$. The four-way interaction with age was non-significant, $F(1, 170) = 1.47$, $p = .227$, $\eta^2_p = .01$, indicating that this developmental trajectory was not significantly different for the type and location conditions. In other words, the results suggested that the CSPC effect was similar whether indexed by stimulus type or location, and that the effect had a tendency to decrease with age in both cases, even though this decrease with age did not reach significance in the location condition when considered separately. There were no effects of interest for error rates.

Awareness of the Context-Specific Proportion Congruency Manipulation

When asked to estimate which context was more difficult, children appeared to be generally unaware of the CSPC manipulation. Across the two groups, 64 out of 174 children (37%) answered that both contexts were equally difficult, 63 out of 174 children (36%) answered that the MI context was more difficult, and 47 out of 174 children (27%) answered that the MC context was more difficult. This distribution was not significantly different from chance, $\chi^2(2) = 3.14$, $p = .214$. Similar patterns appeared in the 5-6 years old group (equally difficult: 33 children, MI more difficult: 30 children, MC more difficult: 23 children;

distribution not different from chance, $\chi^2(2) = 1.84$, $p = .399$) and in the 9-10 years old group (equally difficult: 31 children, MI more difficult: 33 children, MC more difficult: 24 children; distribution not different from chance, $\chi^2(2) = 1.52$, $p = .482$). Similar patterns also appeared when considering the two conditions (type vs. location) separately.

In summary, Experiment 1 found a significant CSPC effect for 5-6 years old children, thus providing the first evidence of a CSPC effect for a population other than adults. We replicated this effect with both location and stimulus type as contextual cues, and it was of similar magnitude whether indexed by location or by stimulus type. Children appeared to be generally unaware of the CSPC manipulation, as is usually the case with adults. Moreover, the effect tended to decrease with age (significantly for stimulus type and descriptively for stimulus location), likely due to the lower interference observed in the 9-10 years old, but incompatible with the hypothesis that implicit control develops throughout childhood. Experiment 2 was designed to strengthen the finding of a CSPC effect in younger children by verifying that it was not driven by learned stimulus-context-control associations (Crump et al., 2006, 2017; Hutcheon & Spieler, 2017). To this end, we again investigated the CSPC effect for location in a group of 5-6 years old children, with a modified design.

Experiment 2

Method

Participants

Data collection was planned for the same sample size as Experiment 1 (which included 45 subjects per condition). Consent was obtained for a new sample of 40 children in kindergarten (19 females and 21 males; mean age = 5.64 years, range = 5.17 to 6.08 years). Recruitment conditions were identical to Experiment 1.

Materials, Procedure and Data Processing

The materials, procedure and data processing were all identical to Experiment 1, except that the task retained only one of the two types of fish (blue fish; see Figures 1b and 1c), and that the fish could go in four directions: down, left, right, or up. Response mappings were changed from Experiment 1 accordingly: children answered using the keys 2, 4, 6 and 8 of the numpad, corresponding to down, left, right, and up targets respectively. As in Experiment 1, trials with a RT faster than 200ms or slower than the subject-specific threshold were dropped from all analyses; for Experiment 2, this removed 11.1% of trials; the maximum was 17% for a given subject.

Design

The design of Experiment 2 retained biased locations (top or bottom): one location was MC (75% congruent) and the other location was MI (25% congruent). Which location was MC and which location was MI was counterbalanced across subjects. The stimuli were divided in two sets. Fish pointing up and down served as inducer items to create a bias in top and bottom locations: these items were 100% congruent in the MC location and 0% congruent in the MI location (to maximize the degree of bias and the likelihood of obtaining a transfer of the CSPC effect; see Crump & Milliken, 2009; Bugg et al., 2020). Fish pointing left and right served as diagnostic items to test the CSPC effect, and were unbiased (50% congruent) in both spatial locations. There was no overlap between the two sets (e.g. a left target could only appear with left flankers or right flankers, not up flankers or down flankers). Inducer and diagnostic items appeared equally often.

As in Experiment 1, children completed eight blocks of 33 trials, and the first trial of each block was excluded; this yielded a total of 256 critical trials. The design is summarized in Table 3. The order of trials within each block was random.

[Insert Table 3 approximately here]

Results and Discussion

One child was excluded (with a flanker effect more than 3SD from the mean), yielding a final sample size of $N = 39$. Descriptive statistics for all measures are displayed in Table 4. The data for this experiment are available at https://osf.io/nyxv8/ [*made available upon publication*].

[Insert Table 4 approximately here]

The analysis verified that a CSPC effect appeared for RTs on diagnostic items, for both RTs and error rates. Inducer items were not analyzed given that there were no congruent trials in the MI location and no incongruent trials in the MC location (see Table 3). Analyses were performed using a 2 (trial type: congruent vs. incongruent) x 2 (context-specific proportion congruency: MC vs. MI) within-subjects ANOVA, restricted to diagnostic items.

For RTs, the analysis showed the expected effect of trial type, indicating faster RTs for congruent trials, $F(1, 38) = 121.62$, $p < .001$, $\eta^2_p = .76$. There was no main effect of CSPC, $F(1, 38) = 0.59$, $p = .447$, $\eta^2_p = .02$. Trial type significantly interacted with CSPC, $F(1, 38) = 4.92$, $p = .033$, $\eta^2_p = .11$. This two-way interaction reflected a CSPC effect: interference was reduced in the MI context (243 ms) when compared to the MC context (281 ms). This 38 ms CSPC effect is represented in Figure 4a. For error rates, there was the expected effect of trial type, indicating more errors for incongruent trials, $F(1, 38) = 21.74$, $p < .001$, $\eta^2_p = .36$, but no main effect of CSPC, $F(1, 38) = 0.82$, $p = .369$, $\eta^2_p = .02$, and no two-way interaction, $F(1, 38) = 0.78$, $p = .383$, $\eta^2_p = .02$. Error rates are represented in Figure 4b.

[Insert Figure 4 approximately here]

As in Experiment 1, children appeared to be generally unaware of the CSPC manipulation. 13 out of 39 children (33%) indicated that the two locations were equally difficult, 14 out of 39 children (36%) indicated that the MI location was more difficult, and 12 out of 39 children (31%) indicated that the MC location was more difficult. This distribution was not significantly different from chance, $\chi^2(2) = 0.15$, $p = .979$.

In summary, Experiment 2 found evidence for a CSPC effect on transfer items in a group of 5-6 years old children, consistent with the hypothesis that these children actually implemented a form of implicit cognitive control to regulate their behavior depending on whether stimuli were presented in a mostly congruent or mostly incongruent context - but incompatible with the alternative account that they just learned associations between a particular stimulus in a particular location and the expected response.

General Discussion

This study performed the first systematic investigation of the CSPC effect in children. Experiment 1 found a significant CSPC effect in a group of 5-6 years old children, and replicated the effect with two different contextual cues - based either on location, or stimulus type. Experiment 2 ensured that this CSPC effect transferred to frequency-unbiased diagnostic items, confirming that the observed effect actually reflects a form of implicit cognitive control, rather than associative learning. The children appeared to be generally unaware of the CSPC manipulation.

In short, our results provide evidence that preschoolers are capable of a surprisingly fine-grained modulation of cognitive control, which allows them to selectively decrease experienced conflict for stimuli that are presented in a mostly incongruent context when compared to stimuli that are presented in a mostly congruent context. This conclusion converges with other recent studies supporting the possibility that young children are capable of effective implicit cognitive control (Gonthier et al., 2021; Ambrosi et al., 2016; Gupta et al., 2009; Iani et al., 2014; Larson et al., 2012; McDermott et al., 2007; Wiersema et al., 2007; Wilk & Morton, 2012), and more generally of effective cognitive control when supported by the situation (Chevalier et al., 2015; Elke & Wiebe, 2017). Our results also extend prior findings of a CSPC effect using a size congruity task in older preadolescent children (Surrey et al., 2019) by showing that the effect exists in a younger age group, can be observed in a common flanker task, and is not driven by associative learning.

Developmental Differences in the CSPC effect

Comparison between 5-6-year-olds and 9-10-year-olds confirmed that the CSPC effect was already well established for preschoolers: far from increasing with age, the CSPC effect appeared to be stronger for the younger age group. This was not due to a ceiling effect in the older age group, as the task was of similar difficulty and elicited levels of interference (around 100 ms) similar to adult versions (e.g. Wendt et al., 2008). To interpret this developmental decrease of the CSPC effect, it is worth recalling that in adults, the CSPC effect is typically in the 15 ms to 30 ms range, or even in the 10 ms to 20 ms range for transfer to unbiased stimuli. In the current study, the CSPC effects obtained in 9-10-year-olds (10 ms for type, 14 ms for location) were thus close to adult results (as was already the case with the results of Surrey et al., 2019, who found no difference between 9-12-year-olds and adults). On the other hand, the CSPC effects obtained in 5-6-year-olds (49 ms for type, 28 ms for location in Experiment 1, 38 ms for the transfer in Experiment 2) were substantially larger.

This type of developmental decrease sometimes occurs for conflict effects (e.g. Gonthier et al., 2021; Marcovitch et al., 2007, 2010; Smulders et al., 2018). One possible interpretation is that conflict effects are simply proportional to baseline performance, with a slower response speed eliciting a proportionally larger congruency effect (e.g. Smulders et al., 2018). Another possibility is that younger children experience greater interference when most stimuli are congruent, possibly due to difficulty in maintaining the task goal, which leaves room for a large improvement in the mostly incongruent condition (Gonthier et al., 2021; see also Marcovitch et al., 2007, 2010). In either case, this would not be a question of younger children having "more implicit control", but a question of implicit control making more of a difference for younger children.

In the present case, it is unclear whether baseline differences of performance fully accounted for the decrease of the CSPC effect with age. Analyzing log-transformed RTs to account for baseline differences in speed still showed a significant decrease with age for CSPC based on type, but a non-significant decrease for CSPC based on location, and a marginally significant decrease for the combination of the two. In any case, the critical point for our purposes is that the CSPC effect clearly did not increase with age, indicating that the basic mechanisms thought to drive the effect - processing a contextual dimension of stimuli irrelevant to the task at hand, implicitly learning the conflict likelihood for various conditions of this dimension, and regulating cognitive control engagement based on these conditions - are indeed functional in young children.

Note that Experiment 1 did not use unbiased diagnostic items, so that children may have partly used complex learning of three-way associations between stimuli, contexts and responses. This is a possible methodological confound for the developmental comparison in Experiment 1. However, there is no reason to believe that it played a major role in driving the larger effect found in younger children: it would be difficult to argue that 5-6-year-olds were better able to learn complex associations of features than 9-10-year-olds. This pattern of larger effects for younger children also closely resembles the one observed for ISPC and LWPC effects, even when diagnostic items are included (Gonthier et al., 2021). A related limitation of our work is that Experiment 2 found a CSPC effect for unbiased items in preschoolers, but we did not collect the same data for 9-10-year-olds. However, given that a CSPC effect for unbiased items was observed for younger children and can also be found in adults (Crump & Milliken, 2009; Crump et al., 2017; King et al., 2012), it is likely that it would also be found in 9-10-year-olds with sufficient statistical power. These considerations do not affect our basic objectives of showing that an unbiased CSPC effect can be observed in preschoolers and that it does not increase with age, which were both achieved.

The Dissociation between Implicit and Explicit Control

The results of this study converge with our prior findings on the LWPC and ISPC effects (Gonthier et al., 2021), in showing that young children are capable of implicitly learning the likelihood of conflict in a given condition (Amso & Davidow, 2012; Aslin & Newport, 2012; Saffran et al., 1996; see also Cohen-Shikora et al., 2018), and tailoring cognitive control engagement to the situation. This surprising level of adaptivity suggests that young children do not specifically struggle with cognitive control, per se: they seem to struggle more specifically with *explicit* cognitive control - regulation of goal-directed behavior performed intentionally and with awareness. Along with the finding that the CSPC effect, like the LWPC and ISPC effects, does not increase with age (Gonthier et al., 2021), this in turn supports the possibility that implicit cognitive control behaves differently from explicit cognitive control (Gonthier et al., 2021).

The literature has identified several steps in implementing explicit cognitive control (see in particular Chevalier, 2015a). Four major components of explicit control could be required to a lesser extent by implicit control, contributing to the relatively greater success of preschoolers (for a detailed discussion, see Gonthier et al., 2021). These are:

1) Monitoring the situation for an explicit cue that could guide behavior: children have difficulties voluntarily attending to goal-oriented cues, and tend to devote more attention to the task stimuli themselves (e.g. Chevalier, 2015a; Karbach & Kray, 2007). In the

case of implicit cognitive control, the cue that signals the need for control is the experience of conflict, which is an intrinsic part of the task.

2) Converting this cue into a goal for action: children experience difficulty when the cue is arbitrary (Towse et al., 2007), and perform better when the cue transparently indicates what they should do (e.g. a color cue to indicate that they should attend the color; Chevalier & Blaye, 2009). In the case of implicit control, experiencing conflict transparently signals the need to decrease processing of the irrelevant dimension and/or increase processing of the relevant dimension.

3) Actively maintaining this goal in memory: children may have difficulties maintaining a task goal in working memory during a delay before it is needed, making it difficult to appropriately regulate behavior (Gonthier et al., 2019). In the case of implicit control, implicitly learned task goals may not require active maintenance in working memory, and each conflicting trial serves as a reminder of the goal (Marcovitch et al., 2007).

4) Actually implementing an action on the basis of this goal when appropriate: children tend to demonstrate goal neglect, failing to act according to a goal even when they are unambiguously aware of that goal (Marcovitch et al., 2007, 2010; Towse et al., 2007; Zelazo et al., 2003). In the case of implicit control, the fact that the act of control is implemented without awareness or intentionality may bypass this requirement.

Developmental research has almost exclusively studied cognitive control under the perspective of explicit cognitive control. This has yielded a substantial body of evidence concerning the difficulties of children with the four components outlined above in explicit control tasks, but how these difficulties manifest - or not - in implicit cognitive control tasks is still unknown. Future research could explore experimental paradigms that allow for the examination and dissociation of these four components in control tasks, with a focus on implicit control. Getting a more precise picture of which role these components play (or do not play) in implicit control tasks would help further understanding of the early success of preschoolers in implicit, but not explicit control tasks.

Possibilities for Further Research

A possibility to extend the present results would be to explore the question of generalizability. Our results confirm that preschoolers can demonstrate a CSPC effect, but the adult literature has tested many different instanciations of the effect, which remain to be investigated in children. Three major types of generalization could be explored here. The first relates to the nature of the task: apart from flanker tasks, the CSPC effect has been observed in task-switching (Crump & Logan, 2010; Leboe et al., 2008), and in the prime-probe Stroop (Crump et al., 2006, 2008). Task-switching paradigms are often used with preschoolers (e.g. Gupta et al., 2009; Karbach & Kray, 2007; Lucenet & Blaye, 2019) and could be usefully extended to include CSPC manipulations. Stroop tasks based on reading are obviously unsuitable for preschoolers, but other variants of the Stroop task could be adapted for this use (e.g. object-color Stroop: Archibald & Kerns, 1999; Prevor & Diamond, 2005). This could help investigate whether the nature of the task matters for CSPC effects to emerge.

A second possible generalization would be to explore other types of contextual manipulations. Apart from the location and stimulus type manipulations tested in the current study, any dimension could potentially be used as a contextual cue: another example is the delay before a stimulus appears (Wendt & Kiesel, 2011). There is also the associated possibility that different contextual cues elicit CSPC effects of different sizes. The adult literature has proposed that stimulus location may be a more salient dimension than incident dimensions of the stimulus such as color or shape, eliciting a larger CSPC effect (e.g. Crump et al., 2008). The opposite pattern was found in the results of Experiment 1, but we compared the "biased location" condition to a "biased type condition" which confounded the color and shape of stimuli, two dimensions that have been traditionally studied separately in adult literature (Crump et al., 2006, 2008; Heinemann et al., 2009; Lehle & Hübner, 2008). It could also be the case that children pay more attention to the shape and color of a stimulus than to other features of a trial (see also Bugg et al., 2020).

A third possible generalization would be to replicate the finding that the CSPC effect transfers to frequency-unbiased stimuli, as shown by Experiment 2. Such transfer has not been consistently observed in the adult literature (see Bugg et al., 2020), which means it is of particular interest to confirm that the current interpretation of the CSPC effect as implicit control (rather than complex associative learning) is correct. Other approaches to testing transfer could be explored in children: for example, another method is to use a task where all stimuli are different (i.e. each stimulus is only seen once; King et al., 2012), which makes it impossible for stimulus-response associative learning to contribute.

All three tests of generalization would be of interest for the adult literature as well as developmental research. In all three cases, it is worth noting that the results of the present study illustrate an unusual reason for exploring CSPC effects in young children instead of adults: the possibility of obtaining larger effect sizes. As discussed above, the CSPC effect is usually of small magnitude in adults, in the 15 ms to 30 ms range; and transfer of the effect to frequency-unbiased stimuli is smaller still, with studies in adults reporting effects in the 10 ms to 20 ms range, which makes it difficult to observe this transfer at all (Crump & Milliken, 2009; Crump et al., 2017). Our study found a CSPC effect in 5-6 years old children that was roughly twice as large as those values, including a significant transfer in Experiment 2. Young children can thus provide an interesting window into effects that are proportionally too small to be reliably observed in adults. This suggests that developmental studies could help solve pending questions in the adult literature, such as the relative contribution of other possible mechanisms to PC effects (e.g. rhythmic or temporal learning: Schmidt et al., 2014; Schmidt, 2016). Thus, the three extensions proposed above are not only interesting to explore the generalization of the CSPC effect in children; they are also interesting to explore the boundary conditions of the effect in general.

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Table 1

Frequency of trial types for Experiment 1

Experimental condition (between-subjects)	Fish	Location	Stimulus			
			>>>>>	<<<<<	>><>>	<<><<
Biased type	Blue fish	Top	24	24	8	8
	Blue fish	Bottom	24	24	8	8
	Yellow fish	Top	8	8	24	24
	Yellow fish	Bottom	8	8	24	24
Biased location	Blue fish	Top	24	24	8	8
	Blue fish	Bottom	8	8	24	24
	Yellow fish	Top	24	24	8	8
	Yellow fish	Bottom	8	8	24	24

Note. Each condition (either biased type or biased location) represents the total number of trials performed over two sessions for a subject in the 5-6 years old group. Displayed is one possible counterbalance in which blue fish are mostly congruent and yellow fish are mostly incongruent (for the biased fish type condition), and the top location is mostly congruent and the bottom location is mostly incongruent (for the biased location condition).

Table 2

Descriptive statistics for Experiment 1

Measure	Condition	CSPC	5-6 years old			9-10 years old		
			CON	INC	INT	CON	INC	INT
RTs	Biased type	MC (75% congruent)	931 (137)	1159 (230)	228	639 (58)	752 (60)	113
		MI (25% congruent)	952 (136)	1131 (202)	179	642 (56)	744 (60)	102
	Biased location	MC (75% congruent)	964 (152)	1171 (227)	207	644 (61)	761 (66)	117
		MI (25% congruent)	969 (164)	1148 (214)	179	649 (55)	752 (67)	103
ERs	Biased type	MC (75% congruent)	.033 (.029)	.130 (.102)	.097	.017 (.018)	.110 (.085)	.093
		MI (25% congruent)	.036 (.039)	.118 (.090)	.082	.015 (.021)	.114 (.064)	.099
	Biased location	MC (75% congruent)	.041 (.031)	.127 (.095)	.086	.022 (.023)	.132 (.090)	.110
		MI (25% congruent)	.038 (.056)	.124 (.081)	.086	.017 (.029)	.101 (.061)	.084

Note. Averages with standard deviations in parentheses. RTs = Response times, ERs = Error rates, CSPC = Context-specific proportion congruency, MC = Mostly congruent, MI = Mostly incongruent, CON = Congruent, INC = Incongruent, INT = Interference (difference between incongruent and congruent).

Table 3

Frequency of trial types for Experiment 2

Location	Flankers	Target			
		<	>	∧	∨
Top	<	16	16		
	>	16	16		
	∧			32	
	∨				32
Bottom	<	16	16		
	>	16	16		
	∧				32
	∨			32	

Note. This is the total number of trials performed over two sessions. Displayed is one possible counterbalance in which the top location is mostly congruent and the bottom location is mostly incongruent. Left and right fish are diagnostic items (50% congruent) whereas up and down fish are inducer items (100% congruent in the MC location and 0% congruent in the MI location); this was the case for all subjects.

Table 4

Descriptive statistics for Experiment 2

Measure	Item type	MC location (75% congruent)			MI location (25% congruent)		
		CON	INC	INT	CON	INC	INT
RTs	Inducer items	1409 (249)	-	-	-	1534 (258)	-
	Diagnostic items	1434 (273)	1715 (350)	281	1445 (271)	1688 (358)	243
ERs	Inducer items	.018 (.020)	-	-	-	.027 (.026)	-
	Diagnostic items	.013 (.020)	.087 (.105)	.074	.012 (.033)	.073 (.095)	.061

Note. Averages with standard deviations in parentheses. RTs = Response times, ERs = Error rates, MC = Mostly congruent, MI = Mostly incongruent, CON = Congruent, INC = Incongruent, INT = Interference (difference between incongruent and congruent).

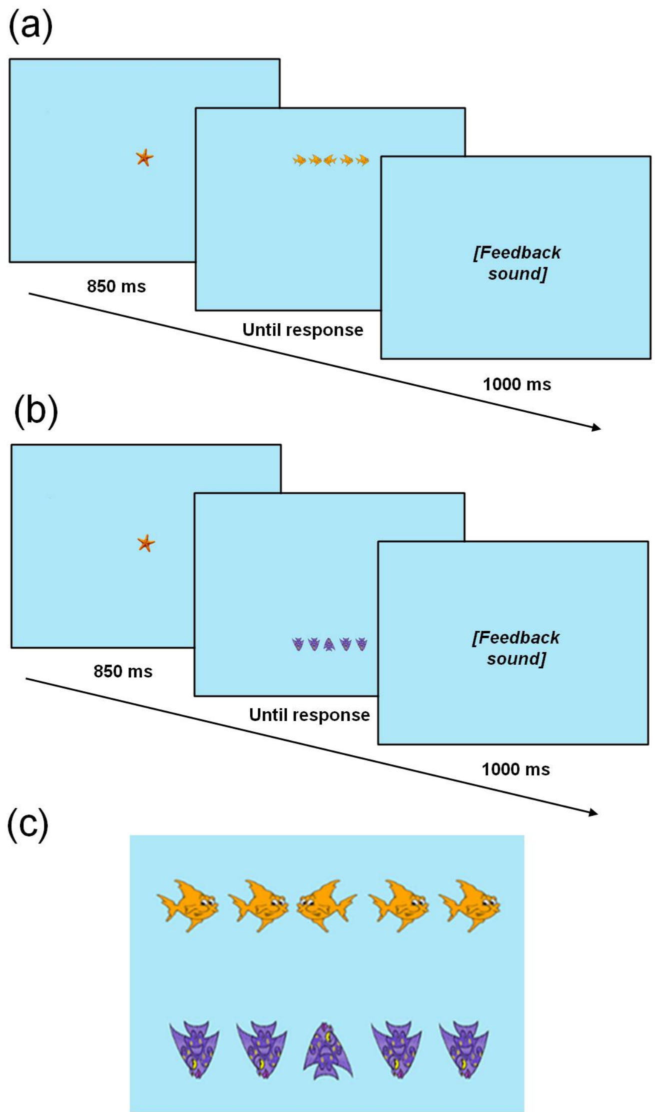

Figure 1. (a) Experimental display for Experiment 1, (b) Experimental display for Experiment 2, and (c) Zoomed-in view of the fish stimuli. Displays for Experiments 1 and 2 are similar, with panels (b) and (c) including an example of up and down fish specific to Experiment 2.

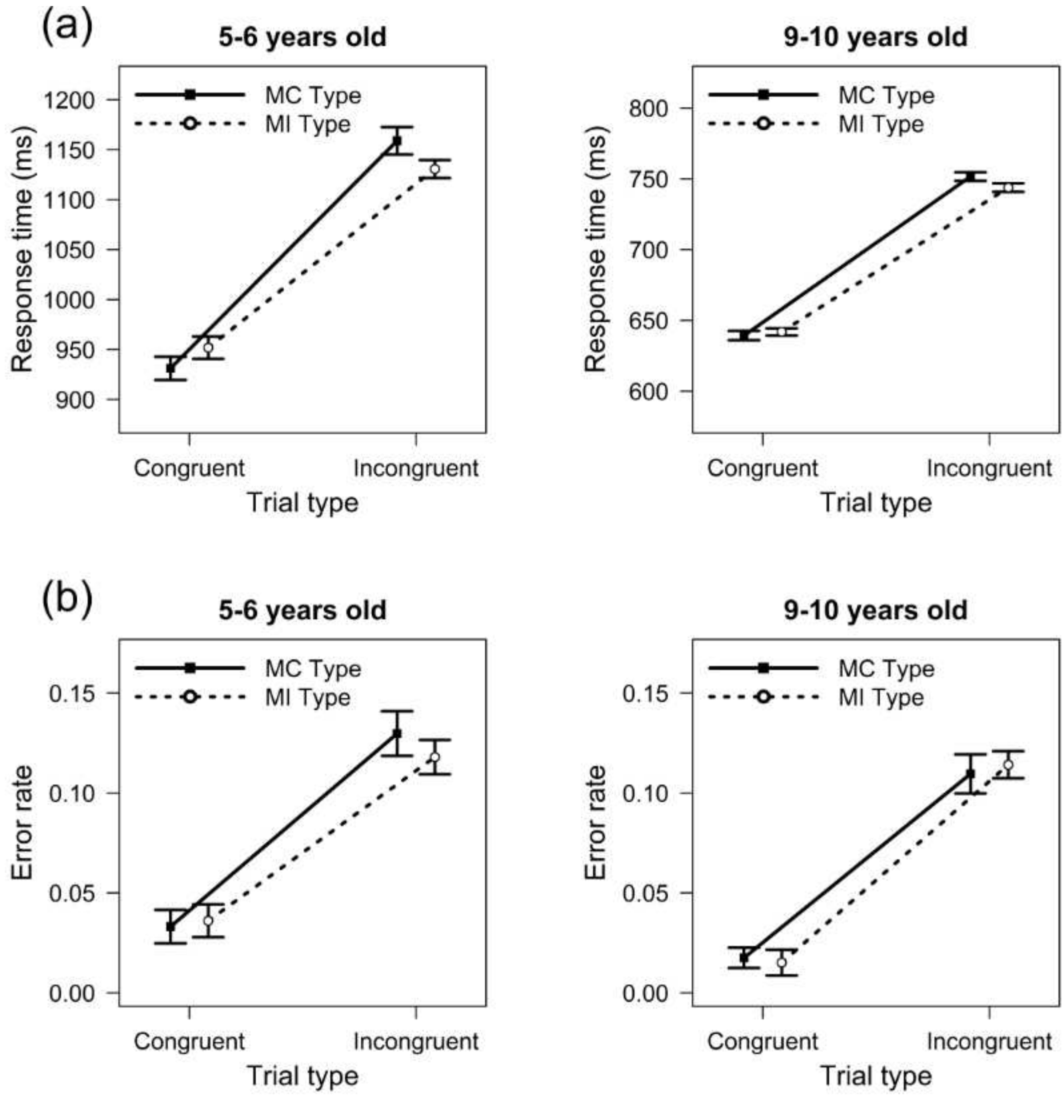

Figure 2. Data for Experiment 1 with context-specific proportion congruency indexed by stimulus type, including (a) Response times and (b) Error rates as a function of age, trial type and context-specific proportion congruency. Error bars represent within-subjects standard errors of the mean (Morey, 2008). Note that the y-axis offset is different for the two age groups in panel (a).

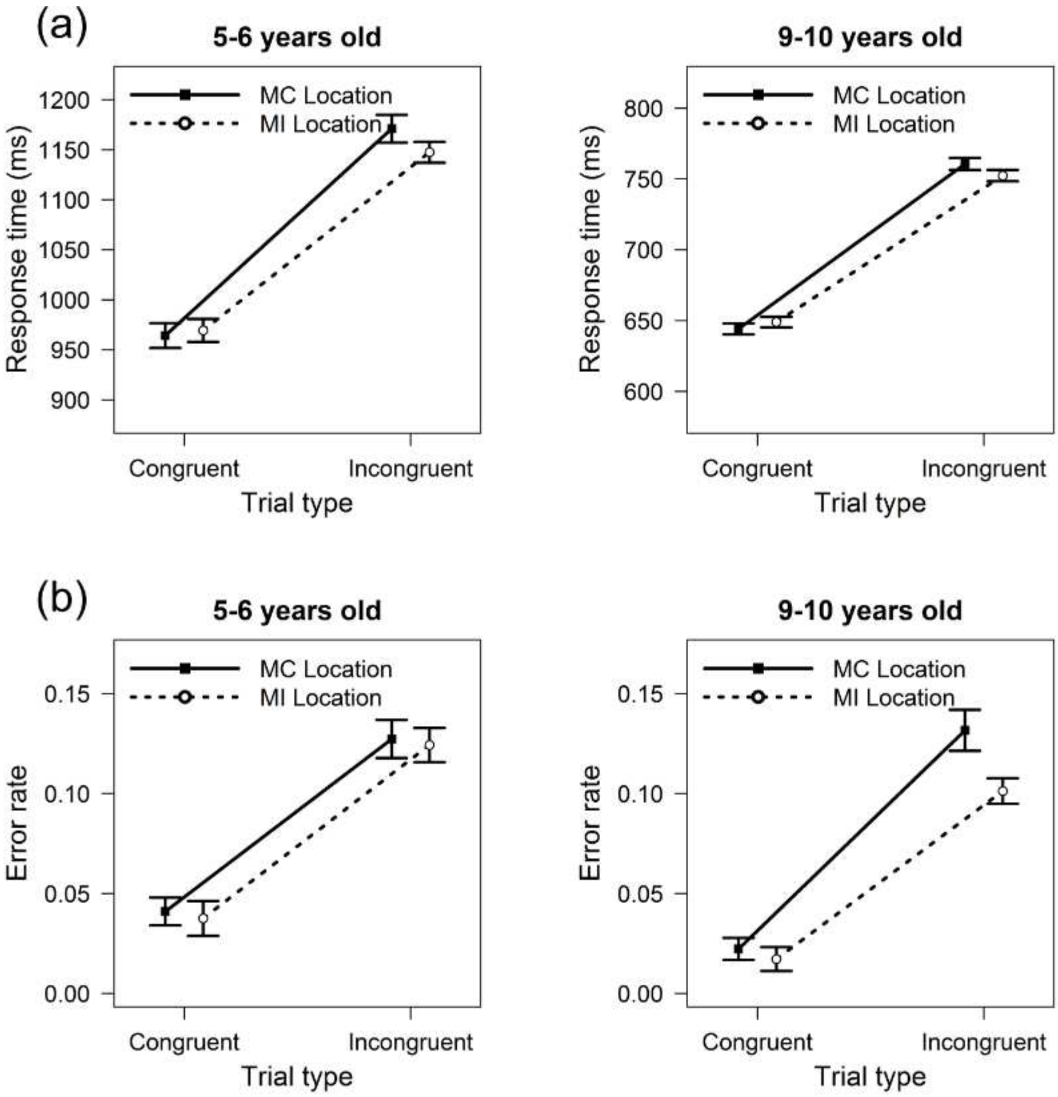

Figure 3. Data for Experiment 1 with context-specific proportion congruency indexed by stimulus location, including (a) Response times and (b) Error rates as a function of age, trial type and context-specific proportion congruency. Error bars represent within-subjects standard errors of the mean (Morey, 2008). Note that the y-axis offset is different for the two age groups in panel (a).

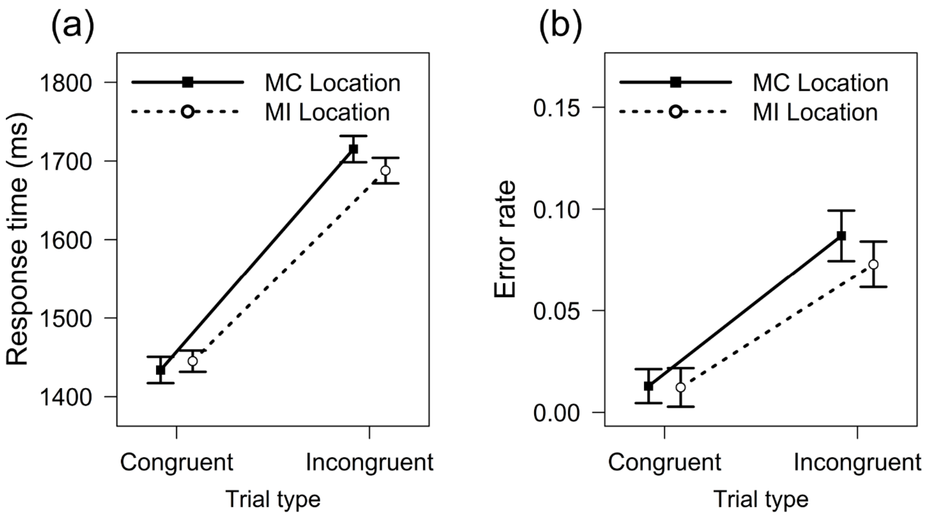

Figure 4. Data for diagnostic items in Experiment 2, including (a) Response times and (b) Error rates as a function of age, trial type and context-specific proportion congruency. Error bars represent within-subjects standard errors of the mean (Morey, 2008).