Developmental changes in cognitive control

Temporal dynamics of task performance across trial sequences

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How do children deal with conflict?
A developmental study of trial-to-trial conflict adaptation
ABSTRACT

This study examined age-related differences in the ability to deal flexibly with conflict, elicited in three tasks requiring the inhibition of prepotent responses; a Simon task, an S-R compatibility (SRC) task and a hybrid Choice-reaction/NoGo task. The primary focus was on developmental change in the ability to adjust performance following a conflict trial, i.e., a trial on which response- and location information do not correspond in the Simon task, a trial requiring a response opposite to the direction indicated by the stimulus in the SRC task, and a NoGo trial in the hybrid Choice-reaction/NoGo task. A secondary aim was to assess whether conflict adjustment follows different developmental trajectories depending on the type of conflict elicited by the tasks. Three age groups (7-9, 10-12 and 18-25-years of age) participated in this study; different participants were recruited for each of the three experiments; one task per experiment. In each experiment, the response-to-stimulus interval was manipulated (50 vs. 500 ms) across trial blocks to assess the time needed for conflict adjustment. The results showed sequential modulation of conflict on all three tasks, although the specific patterns differed between tasks. Importantly, the magnitude of sequential modulation decreased with advancing age, but this developmental trend did not survive when considering age-group differences in basic response speed. The current results contribute to the emerging evidence suggesting that patterns of conflict adaptation are task specific and challenge current interpretations of developmental change in conflict adaptation in terms of top-down control.
INTRODUCTION

The focus of the current study is on executive control of response conflict that may arise on trials of speeded response tasks and, more specifically, on conflict adaptation as manifested in the performance on trials following a conflict trial. Our main aim is to assess developmental trends in conflict adaptation from childhood into young adulthood and to examine whether this trend depends on the specific type of response conflict encountered by the participant.

The typical pattern observed in adult studies of conflict adaptation consists of a substantial reduction in the performance decrement on conflict trials when such a trial is preceded by another conflict trial relative to a non-conflict trial (Duthoo et al., 2014). Although this pattern attracted various interpretations (Egner, 2007; Braem et al., 2014, for reviews; Egner, 2014, for an attempt at reconciliation of different perspectives), the predominant hypothesis suggests that individuals utilize previous conflict information to optimize current conflict resolution (Botvinick et al., 2001). That is, individuals are inclined to expect that (non-) conflict will repeat on the upcoming trial (e.g., Gratton et al., 1992). When they expect a conflict trial to repeat they will up-regulate cognitive control facilitating the processing of relevant stimulus features and the activation of the appropriate response, thereby reducing the performance decrement associated with conflict trials. In contrast, when they expect a non-conflict trial to repeat they will down-regulate cognitive control allowing the processing of irrelevant stimulus features and reducing the threshold for activating the competing, incorrect response. Neurocognitive studies provided convincing support for this view (e.g., Kerns et al., 2004) and the collateral hypothesis of individual differences in top-down cognitive control (e.g., Egner, 2011; Wang, Chou, Potter, & Steffens, 2015).

Surprisingly, there is only a handful studies examining conflict adaptation in children. Collectively, these studies yielded the anticipated pattern of findings reported in the adult literature. That is, a sizeable reduction of the conflict effect on trials following a conflict trial relative to the conflict observed on trials following a non-conflict trial. Stins et al. (2007) presented 12-year-olds with two conflict tasks; a Simon task and an Eriksen flanker task. In the Simon task, a red or green disk was presented left or right from fixation. Children were asked to respond to the color of the disk with a left or right response. The speed and accuracy of their response was evaluated on congruent trials (i.e., trials on which the location of the stimulus corresponded with the location of the response) and incongruent trials (i.e., trials on which the locations of stimulus and response were opposite). In the Eriksen task children were asked to respond to the direction of left- or right-pointing arrows presented at fixation. On half of the trials,
the target arrow was flanked by itself (i.e., congruent trials) and on the other half of the trials the target arrow was flanked by arrows pointing in the opposite direction (i.e., incongruent trials). Stins et al. (2007) observed that conflict adaptation was present on both the Simon task and the Eriksen flanker task. These findings seem to indicate that the mechanisms involved in conflict adaptation are in place already in 12-year-olds.

Iani et al. (2014) examined conflict adaptation in 1st and 2nd graders using a Simon task. They observed that the Simon effect was more pronounced in 1st relative to 2nd graders (65 ms vs. 41 ms, respectively). For 1st graders, the Simon effect decreased from 99 ms on trials preceded by a congruent trial to 33 ms on trials preceded by an incongruent trial. For 2nd graders the corresponding values were, respectively, 72 ms and 12 ms. The size of the conflict adaptation effect did not discriminate between groups. This pattern of findings extends the results reported by Stins et al. (2007) by showing that conflict adaptation is already present in 6-year olds. Iani et al. (2014) interpreted their findings in terms of on-line adjustments in top-down control following response conflict (p. 123).

A similar study has been performed by Ambrosi et al. (2016) who used three different tasks—an Eriksen flanker task, a Simon task and a version of a Stroop task—to assess conflict adaptation in a group of 5- to 6-year-olds. The Stroop task required participants to make a left- vs. right-hand response to the canonical color of a line drawing of a carrot or salad while ignoring the color displayed on the screen. The results reported by Ambrosi et al. (2016) showed a sizable conflict-adaptation effect for the Simon and Stroop tasks (respectively, 114 ms and 156 ms), whereas the effect was considerably less pronounced for the Eriksen flanker task (53 ms). This pattern of results is consistent with previous reports suggesting conflict adaptation in young children. Moreover, the results reported by Ambrosi et al. (2016) indicate that, although conflict adaptation occurs on all three tasks, the size of the effect differs across tasks suggesting specificity in the conflict elicited by each of the tasks (p. 123).

Finally, Cragg (2016) examined developmental change in the resolution of conflict using an Eriksen flanker task. Three age groups (7-, 10- and 20-year olds) performed on an Eriksen task in which interference could occur at the level of stimuli or responses. The results revealed that the sensitivity to stimulus interference decreased between 7 to 10 years while the effect of response interference did not differentiate between age groups. In addition, conflict adaptation was observed for all age groups and the size of this effect was similar across age groups.

The studies reviewed above indicated that conflict adaptation is present already in young children, but they did not evaluate developmental trends in conflict adaptation.
Two studies examined age-related change in conflict adaptation on tasks eliciting a conflict between stopping and going. Huizinga and van der Molen (2011) focused on flexible rule use. They employed an alternating runs paradigm in which a choice task was mixed with a NoGo task. This paradigm allowed them to assess transitions from a NoGo trial to choice reactions relative to sequences of choice reactions. They observed that choice reactions following a NoGo trial were considerably slower than choice reactions following another choice reaction (673 ms vs. 571 ms, respectively). Moreover, the conflict adaptation effect decreased with approximately 100 ms with advancing age from 7-year olds to young adults. Importantly, this developmental trend survived when controlling for age group differences in basic response speed. Huizinga and van der Molen (2011) interpreted their findings to suggest that the inhibition required on NoGo trials results in a lower readiness to respond on the subsequent choice reaction trial. Children would have greater difficulty in the fine-tuning of response thresholds (Huizinga & van der Molen, 2011; p. 499-500).

Van de Laar et al. (2011) examined conflict adaptation using a stop-signal task. In this task, participants were required to respond to the direction of a left- or right-pointing arrow. On a small proportion of trials the color of the arrow changed just following its onset. In one task, the color change indicated to the participants that a response should be withheld (i.e., Global stopping task). In another task, one color of the stop-signal informed the participant to refrain from responding while stop-signals of another color could be ignored (i.e., Selective stopping task). The results indicated that responses following a successful inhibit on a stop-signal trial were slower than responses on choice trials following another choice trial (i.e., 30 ms for the Global stopping task and 26 ms for the Selective stopping task). In contrast to the results observed by Huizinga and van der Molen (2011), there was only a small, and non-significant, developmental trend in the size of the conflict adaptation effect. In this regard, the results reported by van de Laar et al., (2011) contribute to the findings indicating that conflict adaptation varies across tasks depending on the conflict elicited by the task, which in turn may alter the developmental trend that can be observed.

Larson et al. (2012) used a standard Stroop task to examine conflict adaptation in two age groups; 8- to 11-year-olds and 19- to 30-years-olds. The results showed conflict adaptation in both age groups. The Stroop effect in adults decreased from 98 ms following an incongruent trial to 58 ms following a congruent trial. The corresponding values were, respectively, 110 ms and 59 ms in children. The conflict adaptation effect did not discriminate between age groups. Accordingly, Larson et al. (2012) echoed the conclusion of previous studies suggesting that in spite of the underdeveloped neural
mechanisms implicated in cognitive control, children seem to effectively regulate conflict adaptation processes (p. 355).

The results reported by Waxer and Morton (2011) present a challenge to the notions suggesting that conflict adaptation is already present in children. These authors examined developmental change in conflict adaptation using a version of the Dimensional Change Card Sort (Zelazo, 2006). On this task, participants were presented with two target pictures that differ in color and shape (e.g., a blue rabbit and a red truck). They were required to match a series of test pictures to the target pictures by either shape or color. Half of the trials elicited conflict, as the test stimulus could be sorted by either color or shape (e.g., a red rabbit), and half of the trials were neutral, as the test stimulus matches one target stimulus on one dimension (e.g., a blue bar). Three age groups participated in the experiment; 9 to 11-year-olds, 14- to 15-year-olds and young adults. The results revealed that adults and adolescents demonstrated conflict adaptation; that is, the conflict effect decreased following a conflict trial relative to a neutral trial. In contrast, children showed the opposite of conflict adaptation; the conflict effect was larger following a conflict trial relative to a neutral trial. Waxer and Morton (2011) interpreted their data in terms of top-down control, but they suggested that children resort to reactive rather than proactive control measures. That is, adults and adolescents were assumed to use prior conflict to prepare them for potential conflict on the subsequent trial whereas children respond to conflict as it occurs (Waxer and Morton, 2011; p. 1653).

The pattern of results that seems to emerge from the above review examining conflict adaptation in children makes a couple of important points. First, most studies observed conflict adaptation in children suggested that the control mechanisms implicated in conflict adaptation are already in place during childhood (but see Waxer & Morton, 2011). Secondly, only few studies examined developmental change in conflict adaptation and the outcomes of those studies are inconsistent. Thus, Larson et al. (2012) and Cragg (2016) reported that the magnitude of conflict adaptation did not discriminate between adults and children. In contrast, Huizinga and van der Molen (2011) and Waxer and Morton (2011) did report developmental change in conflict adaptation but trends were opposite. Huizinga and van der Molen (2011) observed a developmental decrease whereas Waxer and Morton (2011) reported that in their sample of young children conflict adaptation was absent. Thirdly, research on children’s conflict adaptation showed substantial differences in conflict adaptation between tasks (e.g., Ambrosi et al., 2016). This observation is consistent with results reported in the adult literature suggesting that conflict adaptation is domain specific rather than domain general (for a review Braem et al., 2014). Conflict tasks may differ with regard to the dimensional overlap between the relevant stimulus and response, the irrelevant stimu-
lus or between relevant and irrelevant stimuli (Kornblum & Stevens, 2002). Within this context, the conflict generated in the Simon task is between the irrelevant stimulus (i.e., its location of the respond stimulus) and the relevant response (i.e., a left or right reaction). In a Stroop task, the conflict is quite different due to the dimensional overlap between the relevant stimulus and response, the irrelevant stimulus and response and the relevant and irrelevant response. The conflict elicited in an Eriksen flanker task differs again from the previous ones, in that it is generated by representations of separate stimuli belonging to the same response set (see also Magen & Cohen, 2007). Different types of conflict may require separate modes of control and, indeed, this has been established both in behavioral research (e.g., Funes, Lupianez, & Humphreys, 2010) and neuroscience (e.g., Fan, McCandliss, Flombaum, Thomas, & Posner, 2003). Accordingly, Egner (2014), in reviewing the available evidence, concluded that conflict adaptation involves a complex machinery of bottom-up and top-down modulatory influences the exact implementation of which depends upon the specific conflict encountered. From a developmental perspective one might add that age-related changes in conflict adaptation may depend upon the specific conflict encountered and the modes of cognitive control that are available to the child.

THE CURRENT STUDY

The primary goal of the current study was to examine age-related change in conflict adaptation using three different conflict tasks that are sharing a common implementation format but differ in the type of conflict elicited by the task. That is, participants were asked to respond to colored left- or right-pointing arrows by depressing left- or right-hand response buttons depending upon the color and/or directional information provided by the arrows. The tasks were administered in separate experiments. In the first experiment, participants performed on a version of a standard Simon task. That is, participants responded to the color of the arrow while ignoring the direction indicated by the arrow. Because of the possible overlap between the response and the (irrelevant) directional information associated with the arrow stimulus, responses are relatively fast when the response and arrow direction are congruent and slow when they are incongruent (for a review, Lu & Proctor, 1995). In the second experiment, a stimulus-response compatibility (SRC) task was used in which there is overlap between the relevant stimulus and response set. In this task, the color of the arrow defined the S-R mapping rule; one color signals that the direction of the arrow indicates the responding hand while the other color signals that the opposite response should be executed. Typically, using a blocked presentation of SRC, responses are much faster on compatible relative to incompatible trials (for a review, Proctor & Reeve, 1990), but the speed advantage on compatible trials disappears with a mixed presentation of SRC (e.g.,
Mansfield et al., 2012). In the third experiment, a hybrid Choice-reaction/NoGo task was used. In this task, left-pointing arrows in one color required a left-hand response while left-pointing arrows in the other color required response inhibition and, vice versa, right-pointing arrows in the one color required response inhibition while right-pointing arrows in the other color required a right-hand response. In this task, conflict is elicited by the automatic activation of the response indicated by the direction of the response and the need to suppress this response when the color of the arrow signals that a response to the arrow should be inhibited. This task involves a demanding conjunction analysis of relevant stimulus features (arrow direction and arrow color) and, thus, it can be anticipated that participants are prone to make a substantial amount of commission errors (e.g., McNab et al., 2008).

In view of the inconsistencies reported in the developmental literature, it would be difficult to formulate strong predictions regarding developmental change in conflict adaptation. One prediction can be derived from developmental notions suggesting that the efficiency of top-down cognitive control increases with advancing age (e.g., Davidson et al., 2006; Luna et al., 2010; Munakata et al., 2012). On this hypothesis, it would be predicted that the conflict-adaptation effect should increase with advancing age, as suggested by the findings reported by Waxer and Morton (2011) (but see Huizinga & van der Molen, 2011). Another prediction can be derived from the literature suggesting the domain-specificity of conflict adaptation (e.g., Braem et al., 2014). This prediction states that the conflict adaptation effect will differ across tasks, as the conflicts elicited in the three tasks may be qualitatively different. Thus, the conflict in the Simon task arises from the overlap between an irrelevant stimulus feature (the direction of the arrow) and the location of the response, whereas in the other two tasks the conflict results from the interference between the S-R mappings in accordance with the instructions and the overlap between relevant stimulus features and the set of responses. Differences in conflict adaptation between the latter two tasks are anticipated as well. On incompatible trials in the SRC task, the conflict is between two competing responses; i.e., a pre-potent response indicated by the direction of the arrow vs. the opposite response according to the task instructions. On NoGo trials in the hybrid Choice-reaction/NoGo task, the conflict is between response activation to the stimulus vs. the inhibition of this response required by the task instructions. Moreover, the conjunction analysis required on this task may impose stronger demands on working memory, thereby increasing the conflict-adaptation effect (e.g., Ambrosi et al., 2016; Duthoo et al., 2014). Finally, given the hypothesis that conflict adaptation involves top-down cognitive control (e.g., Kerns et al., 2004), performance adjustments may need some time to be implemented. Previously, Notebaert et al. (2006) observed that adaptation to Stroop conflict did not occur in adults when the stimulus-to-response (RSI) was very short (i.e., 50 ms) while
it was clearly visible when RSI was lengthened to 200 ms. In the current study, RSI was manipulated (in pure blocks) to be either 50 ms or 500 ms. Accordingly, it was predicted that age-related change in conflict adaptation would be visible only when RSI was long but not when it was short. When RSI is short neither adults nor children have sufficient time for the configuration of control measures required for performance adjustments.

EXPERIMENT 1: CONFLICT ADAPTATION ON A SIMON TASK

The current version of the Simon task required participants to respond to the color of left- or right-pointing arrows while ignoring the directional information associated with the arrows. On half of the trials the location of the response, right- or left-hand response, corresponds with the direction indicated by the arrow, right or left, respectively, whereas on the other half of the trials the location of the response does not correspond with arrow direction. The former type of trials is dubbed ‘congruent’ and the latter ‘incongruent’. Numerous studies indicate that the task-irrelevant spatial information associated with respond stimuli in a Simon paradigm has a relatively small but robust effect on the speed of responding—the speed of responding is delayed on incongruent relative to congruent trials (review in Lu & Proctor, 1995). This delay has been attributed to the need to suppress the pre-potent response towards the location indicated by the stimulus (e.g., Eimer, 1999; Miles & Proctor, 2012).

On the hypothesis assuming that the ability to inhibit a pre-potent response develops rapidly during childhood (e.g., Dempster, 1992; van der Molen, 2000), one would be led to predict a decrease in the Simon effect with advancing age. Unfortunately, the relatively scant developmental literature yielded inconsistent findings. Jerger et al. (1999) reported a developmental decrease of the Simon congruency effect using an auditory variety of the Simon task (e.g., responding to the speaker's gender while ignoring the speaker's location). Band et al. (2000) used an inter-modal Simon task requiring participants to respond to a visual stimulus while ignoring the location of a task-irrelevant auditory stimulus that was presented at different intervals following the onset of the visual stimulus. The only developmental difference was a larger Simon congruency effect for auditory accessories presented at longer intervals. Finally, Davidson et al. (2006) presented age groups with visual implementations of a Simon task differing in the type of visual stimulus (e.g., pictures, arrows, dots). They observed a developmental decrease in the Simon congruency effect for one task (presenting pictures) but not others (presenting arrows).

One aim of this experiment was to obtain a solid pattern of developmental change in the Simon congruency effect. The major goal of this experiment was, however, to
replicate the recurrent finding of conflict adaptation in the Simon task (for a review, Kerns, 2006) and to assess whether conflict adaptation would develop with advancing age. Recently, Ambrosi et al. (2016) observed a substantial Simon effect (48 ms) in 5-year olds and, most interestingly, the Simon effect was 105 ms on trials following a congruent trial whereas it was annihilated on trials following an incongruent trial. Thus, it was anticipated that a similar pattern would be observed here for the long RSI. Moreover, the current results should reveal a developmental trend assuming that conflict adaptation is a manifestation of top-down cognitive control. Such a developmental trend should be absent for the short RSI as both children and adults would need more time for the instantiation of appropriate conflict adaptation.

METHOD

Participants
Three age groups (N = 65) between 7-25 years of age participated in the experiment; a group of 21 young children between 7 and 9-years of age (M = 7.9 years; 12 girls), a group of 20 older children between 10 and 12-years of age (M = 11.4 years; 12 girls, and a group of 24 young adults between the ages of 18 and 25 (M = 21.0 years; 17 females) enrolled in the experiment. The children were selected with the help of their schools and with permission of their caregivers. All children had average or above average intelligence based on teacher reports. The young adults were undergraduate psychology students. They were recruited by flyers and received course credits for their participation. All participants reported to be in good health and had normal or corrected-to-normal vision. Informed consent was obtained from adult participants and primary caregivers of the children. All procedures were approved by the Ethical Review Board of the University.

Apparatus and stimuli
The experiment was run on 12-, and 15-in. screen computers and laptops. Stimuli were presented at the center of the screen, against a white background. The stimuli were left- vs. right-pointed arrows in red or blue and measuring 1.5 cm length and width. Participants viewed the monitor from a distance of 40-60 cm, and responded to the stimuli by pushing the ‘z’ key with their left-index finger or the ‘/’ key with their right-index finger. These keys are on the bottom row of a ‘qwerty’ keyboard. The computer coded response accuracy and registered the speed of responding to the nearest millisecond. Reaction time (RT) was recorded as the time between stimulus onset and the moment that one of the response keys was switched. The response triggered the offset of the stimulus and started the response-to-stimulus interval (RSI), which was fixed at either 50 or 500 ms.
Design and procedure
Participants performed a choice RT task in which they made a binary response to the color of the arrow while ignoring arrow directions. Red arrows required a left-hand response and blue arrows a right-hand response, or vice versa (counterbalanced across participants). An experimental session consisted of 10 experimental blocks; 5 short RSI blocks (50 ms) and 5 long RSI blocks (500 ms). Each RSI condition started with a 50-trial practice block, followed by the five experimental blocks consisting of 100 trials. The order of the RSI conditions was counterbalanced across participants.

RESULTS AND DISCUSSION
For each age group and RSI, trials were sorted for Current trial congruence (congruent vs. incongruent current trials), and Preceding trial congruence (congruent vs. incongruent preceding trials).

Error rate
Errors and trials following an error were excluded from RT sorting. Error rates and median RTs are presented in Table 1, for each of the above trial categories. Error rates were square-root transformed prior to further analysis. Error rates were relatively low (5.0%) and decreased with advancing age (5.8, 5.1, and 4.3 % for children, older children, and young adults).

Table 1. Mean RT (ms) and Error Rate (%) for each trial sequence, RSI and age group (Experiment 1).

<table>
<thead>
<tr>
<th>Trial Sequences</th>
<th>RSI-50</th>
<th>RSI-500</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age Group</td>
<td>C-C</td>
<td>C-IC</td>
</tr>
<tr>
<td>7-9 yrs</td>
<td>558.30</td>
<td>723.08</td>
</tr>
<tr>
<td>10-12 yrs</td>
<td>529.30</td>
<td>651.73</td>
</tr>
<tr>
<td>18-25 yrs</td>
<td>435.38</td>
<td>509.34</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trial Sequences</th>
<th>RSI-50</th>
<th>RSI-500</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age Group</td>
<td>C-C</td>
<td>C-IC</td>
</tr>
<tr>
<td>7-9 yrs</td>
<td>4.6</td>
<td>5.6</td>
</tr>
<tr>
<td>10-12 yrs</td>
<td>5.2</td>
<td>4.7</td>
</tr>
<tr>
<td>18-25 yrs</td>
<td>4.5</td>
<td>5.1</td>
</tr>
</tbody>
</table>

Note. C-C: current Congruent trial preceded by a Congruent trial; C-IC: current Incongruent trial preceded by a Congruent trial; IC-C: current Congruent trial preceded by an Incongruent trial; IC-IC: current Incongruent trial preceded by an Incongruent trial.
adults, respectively), \( F(2, 62) = 6.19, p < .004, \eta^2_p = .17 \). The Simon congruency effect on error rate did not reach significance; 5.1 and 5.0% on congruent vs. incongruent trials, respectively, \( p > .35 \), and was not influenced by congruency on the preceding trial, \( p > .92 \). Error rates correlated positively with RTs. Thus, the current findings rule out explanations in terms of speed accuracy trade-off.

**Response speed**

The speed of responding increased with advancing age, \( F(2, 62) = 80.84, p < .001, \eta^2_p = .72 \). Adults responded faster (\( M = 437 \text{ ms} \)) than both older (\( M = 581 \text{ ms} \)) and younger children (\( M = 626 \text{ ms} \)). Follow-up tests indicated that each age group differed significantly from the other; \( ps < .001 \) for comparisons between adults vs. both groups of children, and \( p < .023 \) for the comparison between both child groups, \( \eta^2_ps > .17 \). RTs were longer to the short RSI, 566 ms, compared to the long RSI, 530 ms, \( F(1, 62) = 33.50, p < .001, \eta^2_p = .35 \). The RSI effect increased with advancing age; young children, 13 ms, older children, 31 ms, young adults, 62 ms, \( F(2, 62) = 5.79, p < .005, \eta^2_p = .16 \).

As anticipated, the Simon effect was altered significantly by Congruency on the immediately preceding trial, \( F(1, 62) = 383.74, p < .001, \eta^2_p = .86 \). The Simon effect was considerably larger on trials preceded by a congruent trial (\( M = 121 \text{ ms} \)) relative to an incongruent trial (\( M = 38 \text{ ms} \)). Notably, the Trial sequence effect interacted with the effect of Age group, \( F(2, 62) = 34.21, p < .001, \eta^2_p = .53 \) and RSI, \( F(1, 62) = 36.79, p < .001, \eta^2_p = .37 \). This interaction was qualified by a higher-order interaction comprising RSI, Age group and Trial sequence, \( F(2, 62) = 24.52, p < .001, \eta^2_p = .44 \). This interaction is plotted in Figure 1. It can be seen that there is a sizeable Simon effect on trials following a congruent trial associated with both the 50 ms RSI (left panel of the figure) and the 500 ms RSI (right panel). The Simon effect is considerably smaller on trials following an incongruent trial for the 500 ms RSI and basically annihilated on trials following an incongruent trial for the 50 ms RSI. The data suggest that the trial-to-trial modulation decreases with advancing age for both RSIs.
Follow-up analyses were performed for both RSIs, separately. The analysis performed on the data associated with the 50 ms RSI indicated that the trial-to-trial modulation of the Simon effect was significant in all three age groups (ps < .001). In addition, the size of the trial-to-trial modulation effect decreased with advancing age, $F(2, 62) = 43.47$, $p < .001$, $\eta^2_p = .58$, with each age group differing significantly from the other (ps < .002). However, a subsequent analysis, controlling for age-group differences in basic response speed, revealed that the apparent age-related change in conflict-adaptation was not disproportional. The analysis of the results associated with the 500 ms RSI yielded a significant conflict-adaptation effect in all three age groups (ps < .001), but the apparent age-related trend failed to reach significance ($p > .16$).

At this point, it should be noted that conflict adaptation has been argued to be due primarily to the repetition of features across trial sequences rather than top-down control (e.g., Mayr, Awh, & Laurey, 2003). Indeed, it has been observed that the apparent conflict adaptation effect occurs only or more strongly on trials repeating features of the immediately preceding trial. Accordingly, conflict-adaptation would be due to a lower-order repetition priming rather than conflict-driven control adjustments (for a review Schmidt et al., 2015). The current data-set did not contain a sufficient number of trials for a full examination of the repetition-priming account of conflict adaptation. Thus, we averaged data across the two RSIs and categorized trial sequences in terms of repetitions vs. alternations of arrow direction. The analysis revealed that the Simon
effect following congruent trials was somewhat larger, albeit significantly, for feature repetitions relative to alternations, respectively 126 ms vs. 116 ms, $F(1, 62) = 4.45, p < .04, \eta^2_p = .07$. This pattern reached significance in adults only, $p < .028, \eta^2_p > .19$, but not in both child groups, $p_S > .11$.

In conclusion, the current results yielded a pronounced Simon effect that decreased in magnitude with advancing age replicating previous results (Davidson et al., 2006; Jerger, 1999; but see Band et al., 2000). Consistent with adult studies, the current results showed that the Simon effect was considerable reduced on trials following an incongruent trial relative to a congruent trial (e.g., review in Kerns, 2006). This sequential modulation pattern was different between the 50 ms and 500 ms RSI. For both RSIs, there was a robust Simon effect on trials preceded by a congruent trial. For the 500 ms RSI, the Simon effect was considerably reduced on trials preceded by an incongruent trial whereas the Simon effect on trials following an incongruent trial was basically annihilated when the RSI was 50 ms. The apparent age-related change in the sequential modulation pattern failed to reach significance for the results associated with the 500 ms but showed a significant downward trend for the results associated with the 50 ms. It should be noted, however, that this trend was not disproportional.

Three results that emerged from this experiment are noticeable. First, the results associated with the 50 ms RSI showed that the Simon effect observed on trials following a congruent trial was annihilated on trials following incongruent trials. This result stands in contrast with findings reported in the adult literature suggesting that conflict adaptation does not occur when the RSI is short. Thus, Notebaert et al. (2006) observed that conflict modulation, which was clearly present when the RSI was 200 ms, was absent when RSI was reduced to 50 ms. From this observation, it was concluded that conflict modulation needs some time to be configured. However, the current findings present a challenge to this conclusion. The apparent discrepancy between the current findings and the results reported previously by Notebaert et al. (2006) could be due to the use of different tasks. Notebaert et al. (2006) examined the time course of conflict adaptation using a version of a Stroop task whereas a Simon-task was used in the present Experiment. In this regard, the current finding would add to the literature emphasizing the domain specificity of conflict-adaptation effects (e.g., Braem et al., 2014).

The second result that stands out refers to the observation that the size of the conflict modulation in children did not differ from adults. If anything, the size of the effect was larger in young children compared to adults, albeit not significant for the 500 ms RSI and not disproportional for the 50 ms RSI. Given the abundant literature suggesting that cognitive control follows a protracted developmental course (Albert & Steinberg,
How do children deal with conflict?

2011; Anderson, 1998; Best & Miller, 2010; Best, Miller & Naglieri, 2011; Hughes, 2011; Huizinga et al., 2006; Luciana & Nelson, 2002; Lyons & Zalazo, 2011; Romine & Reynolds, 2005; Tamnes et al., 2010; Vuontela et al., 2013) and studies suggesting that young children readily resort to reactive control rather than adopting a proactive control strategy (Chatham et al., 2009; Munakata et al., 2012), one would be led to predict that the conflict-adaptation effect would be larger in adults compared to children, not smaller.

Finally, the analysis examining the potential contribution of repetition vs. alternation effects in conflict adaptation revealed that these effects interact with conflict modulation in adults but not in the child groups. This observation is in accord with the results reported by Waxer and Morton (2011). These authors examined whether associative priming influenced their results by removing exact stimulus repetition trials from the analysis of developmental change in conflict adaptation. This restricted analysis indicated that associative priming did not meaningfully change the developmental pattern observed when considering the full dataset.

EXPERIMENT 2: CONFLICT ADAPTATION ON A S-R COMPATIBILITY (SRC) TASK

In the present version of the SRC task, the stimuli were identical to those used in the previous experiment. Participants were asked to respond to the direction of the central arrow stimuli. The arrows were presented in two different colors; one color instructed participants to make a spatially compatible response (i.e., a left-hand response to a left-pointing arrow and a right-hand response to a right-pointing arrow), whereas the other color of the arrows instructed participants to make a spatially incompatible response to the direction of the arrow (i.e., a left-pointing arrow requires a right-hand response and a right-pointing arrow requires a left-hand response). Importantly, arrow color was mixed within trial blocks. The mixing of compatible and incompatible trials has been observed to annihilate the response speed advantage of compatible over incompatible trials when presented in pure blocks (e.g., Christensen, Ivkovich, & Drake, 2001; De Jong, 1995; Heister & Schroeder-Heister, 1994; Proctor & Vu, 2002; Shaffer, 1965; Stoffels, 1996; van Duren & Sanders, 1988; Vu & Proctor, 2004). More specifically, compatibility mixing reduces the speed of responding on compatible trials relative to blocked presentation, whereas presentation mode has only a minor effect on the speed of responding on incompatible trials. This pattern has been taken to suggest that compatibility mixing induces a strategic bias towards incompatibility resulting in an active suppression of the compatible mapping rule, thereby reducing the SRC effect on the speed of responding (e.g., De Jong et al., 1994).
Developmental studies examining spatial SRC effects are few and far between. Early studies by Clark (1982) and Lávadas (1990) showed a developmental decrease in the SRC effect on the speed of responding. Van den Wildenberg and van der Molen (2004) reported a similar pattern that was interpreted to suggest that children experience greater difficulty than adults in inhibiting the over-learned directional response to the stimulus. Other studies, however, reported developmental stability rather than age-related change in the SRC effect. Wright and Diamond (2014), for example, examined SRC effects across a limited age range (from 6 to 10-years) and observed that for all ages the speed of responding was considerably faster on compatible relative to incompatible trials. Casey et al. (2002) reported that the cost of an incompatible relative to a compatible mapping did not differ between a child group (7- to 11-years) and a group of young adults. Similarly, Dornier and Meaney (2003) reported a pronounced SRC effect that did not change with advancing age. At this point, it is difficult to provide a ready interpretation of the apparent inconsistencies between studies. Finally, to date there is only one developmental study in which SRC was manipulated between and within trial blocks (Crone et al., 2004). This study examined age-related change in the flexible use of SRC mappings in three different age groups; 8-year-olds, 11-year-olds and young adults. The results revealed that SRC mixing annihilated the SRC effect observed for pure blocks but only when responses across trials alternated, not when responses were repeated. Importantly, the interaction between trial block (pure vs. mixed) and SRC mapping (compatible vs. incompatible) did not vary across age groups.

The goal of this experiment was to examine developmental change in conflict adaptation using an SRC task with a mixed presentation of compatible and incompatible trials. Consistent with previous studies, we anticipated that the typical SRC pattern associated with pure blocks (i.e., slower responses on incompatible relative to compatible trials) would be greatly reduced, or even absent, when using mixed SRC blocks (e.g., van Duren & Sanders, 1992; Stoffels, 1996). When examining trial sequence effects, we predicted obtaining a greatly reduced or even reversed SRC effect on trials following an incompatible trial relative to a compatible trial (e.g., Jennings, van der Molen, van der Veen, & Debski, 2002; Mansfield et al., 2012). On the hypothesis that the reduction of the SRC effect following an incompatible trial reflects top-down cognitive control (De Jong, 1995; Jennings et al., 2002; Mansfield et al., 2012), we predicted that the reduction of the SRC effect following an incompatible trial would be more prominent with advancing age.
METHOD

Participants
Participants (N = 64) were recruited from three age groups. There were two groups of children; 23 children between 7 and 9 years of age (M = 8.2 years; 14 girls) and 21 children between 10- and 12-years of age (M = 11.7 years; 11 girls). Finally, a group of 20 young adults between the ages of 18 and 25 (M = 22.3 years; 15 females) enrolled in the experiment. The children were selected with the help of their schools and with permission of their caregivers. All children had average or above average intelligence based on teacher reports. The young adults were undergraduate psychology students. They were recruited by flyers and received course credits for their participation. All participants reported to be in good health and had normal or corrected-to-normal vision. All procedures were approved by the Ethical Review Board of the University.

Apparatus and stimuli
All details concerning the apparatus and stimuli were the same as in Experiment 1.

Design and procedure
Participants were asked to respond to the direction indicated by blue arrows and in the opposite direction to red arrows, or vice versa (counterbalanced across participants). All other design details were the same as in Experiment 1.

RESULTS AND DISCUSSION

For each age group, trials were sorted for Current compatibility (compatible vs. incompatible current trials), Preceding compatibility (compatible vs. incompatible preceding trials), and RSI (50 vs. 500 ms). Errors and trials following an error were excluded from RT sorting. Error rates and median RTs are presented in Table 2, for each of the above categories. Error rates were square-root transformed prior to analyses.

Error rate
In Table 2 it can be seen that error rates are relatively low (≤ 8.2%). Error rates decreased with advancing age (from 7.5% in young children, to 7.2% in older children and 5.8% in adults), F (2, 61) = 12.53, p < .001, η²p = .29. Error rate was only slightly higher on incompatible (M = 6.9%) than compatible trials (M = 6.7%), F (1, 61) = 15.22, p < .001, η²p = .20, and this effect differed across age groups, F (2, 61) = 22.46, p < .001, η²p = .42. Adults and young children made more errors on incompatible than compatible trials (5.7% vs. 5.9% for adults, 7.2% vs. 7.8 % for young children, ps < .001). Older children showed the opposite pattern (7.3 vs. 7.0%), p < .016. The interaction between RSI and
Current compatibility was not significant, \( p > .20 \), but both effects were included in a complex higher-order interaction; Current compatibility \( \times \) Preceding compatibility \( \times \) Age group and RSI, \( F(2, 61) = 32.99, p < .001, \eta^2_p = .52 \).

In the bottom panel of Table 2, it can be seen that error rate in young children and adults, but not older children, is somewhat lower on incompatible trials preceded by another incompatible trial relative to incompatible trials followed by a compatible trial when RSI is short. This pattern changes into its opposite when RSI is long (i.e., both young children and adults did not show any error rate differences between both trial sequences, but older children made more errors on IC-IC as compared to C-IC sequences). Finally, error rates correlated negatively with the speed of responding indicating that the RT patterns reported below cannot be attributed to shifts in speed-accuracy tradeoff.

**Response speed**

The speed of responding increased with advancing age, \( F(2, 61) = 190.72, p < .001, \eta^2_p = .86 \). Adults responded faster (\( M = 687 \) ms) than older (\( M = 805 \) ms) and younger children (\( M = 956 \) ms). Follow-up tests indicated that each age group differed significantly from the other (\( ps < .001 \)). Responses were faster to a long RSI (\( M = 753 \) ms) compared to a short RSI (\( M = 879 \) ms), \( F(1, 61) = 163.04, p < .001, \eta^2_p = .73 \). The RSI effect was stronger in children compared to young adults, \( F(2, 61) = 4.70, p < .013, \eta^2_p = .13 \).
As anticipated, there was little difference in the speed of responding between compatible, 801 ms, vs. incompatible trials, 831 ms, \( p > .16 \). The apparent elimination of the typical SRC effect (i.e., slower responses on incompatible than compatible trials), due to the mixed presentation of SRC mappings, was present for each age group; i.e., the main effect of SRC did not interact with the effect of Age group (\( p > .90 \)). Importantly, there was a highly significant trial-by-trial modulation of the SRC effect, \( F (1, 61) = 565.64, p < .001, \eta^2_p = .90 \). Compatible responses were considerably faster than incompatible responses when the preceding trial was compatible (\( M = 689 \) ms vs. \( M = 914 \) ms, respectively). When the current trial followed an incompatible trial, however, the SRC effect changed into its opposite (\( M = 936 \) ms for compatible trials vs. \( M = 727 \) ms for incompatible trials). This pattern is consistent with previous studies (e.g., Jennings et al., 2002; Mansfield et al., 2012) and indicates that the S-R compatibility effect is not eliminated by the mixed presentation of SRC. The trial sequence effect was altered by RSI, \( F (1, 61) = 9.70, p < .003, \eta^2_p = .14 \). For the 50 ms RSI, the SRC effect was 248 ms for trials preceded by a compatible trial and -226 ms when the preceding trial was incompatible. For the 500 ms RSI, these values were, respectively, 202 ms and -192 ms.

There was a highly significant interaction between the effects of Current SRC, Preceding SRC, and Age group, \( F (2, 61) = 7.47, p < .001, \eta^2_p = .20 \), suggesting a developmental trend in conflict adaptation. This interaction is plotted in Figure 2. The figure indicates that SRC on the preceding trial alters the SRC effect on the current trial and this effect is stronger for the youngest children relative to the two older age groups. It should be noted, however, that the higher-order interaction did not survive when Group RT was included as covariate, \( p > .54 \). The higher-order interaction including RSI was not significant (\( p > .63 \)).

Finally, as in the previous experiment, we averaged the data across RSIs to evaluate repetition effects on the trial sequence effect on S-R compatibility. The analysis indicated that response repetition significantly altered the trial sequence effect on S-R compatibility, \( F (1, 61) = 192.4, p < .001, \eta^2_p = .75 \). That is, for response repetitions the S-R compatibility effect was 325 ms when the preceding trial was compatible relative to -307 ms when the preceding trial was incompatible. For response alternations, these values were much smaller; respectively, 125 ms and -110 ms. These effects did not discriminate between age groups, \( p > .11 \).

In conclusion, the current results are consistent with the recurrent finding that mixing SRC trials within blocks eliminates the typical SRC effect (e.g., De Jong, 1995; Stoffels, 1996; van Duren & Sanders, 1992) or changes the SRC effect into its opposite (e.g., Mansfield et al., 2012). The current study adds to this literature by showing that the...
reversal of the SRC effect associated with mixed blocks occurs in each of the participating age groups. Importantly, the results showed a trial-by-trial modulation effect. That is, a typical SRC effect was observed following a compatible trial, but a reversal of the SRC effect occurred on trials following an incompatible trial. This finding is consistent with previous findings (e.g., Jennings et al., 2002; Mansfield et al., 2012) and suggests that mixing does not eliminate SRC effects.

The sequential modulation effect decreased with advancing age and was not influenced by associative priming. However, the developmental trend in conflict adaptation was not disproportional when considering global group differences in the speed of responding. Finally, in contrast to expectations derived from the results reported by Notebaert et al. (2006), the conflict adaptation effect was larger on trial blocks with a 50 ms RSI relative to effect associated with a 500 ms RSI. This pattern is similar to the findings obtained in the previous experiment using a Simon task and, thus, suggests that it is not task-specific.

![Graph showing reaction time difference (ms), including standard error bars, between current incompatible vs. compatible trials (i.e., SRC effect) for preceding incompatible (IC) and compatible (C) trials, and for each age group.]

Figure 2. Reaction time difference (ms), including standard error bars, between current incompatible vs. compatible trials (i.e., SRC effect) for preceding incompatible (IC) and compatible (C) trials, and for each age group.
EXPERIMENT 3: CONFLICT ADAPTATION ON A HYBRID CHOICE-REACTION/NOGO TASK

We used a hybrid Choice-reaction/NoGo task task derived from van Boxtel, van der Molen, Jennings, and Brunia (2001). In this task, a left- or right-pointing arrow is presented in red or blue color. The combination of arrow direction and color determines whether a response should be executed or withheld. Thus, a red and left-pointing arrow may require a left-hand response while a red and right-pointing arrow requires response inhibition or a blue and right-pointing arrow may require a right-hand response while a blue and left-pointing arrow may ask for response inhibition. Adult findings derived from a variety of Go/NoGo tasks showed that the speed of responding is delayed on Go trials following a NoGo trial relative to a Go trial (e.g., Hoffmann et al., 2003; Kleinsorge & Gajewski, 2004; Rieger & Gauggel, 1999; Rieger et al., 2003; Schuch & Koch, 2003).

In the developmental literature, Go/NoGo tasks have been widely used to examine age-related changes in the ability to inhibit pre-potent responses (e.g., Brocki & Bohlin, 2004; Casey et al., 1997; Cragg & Nation, 2008; Durston et al., 2002; Garon et al., 2008; Hammerer et al., 2010; Huizinga & van der Molen, 2011; Iida, Miyazaki, & Uchida, 2010; Johnstone et al., 2007; Jonkman et al., 2003; Levin et al., 1991; Luria, 1961; Span et al., 2004). The results of most studies employing the Go/NoGo task converge on the conclusion that the ability to inhibit a pre-potent response develops rapidly during childhood and reaches mature levels when children enter the adolescent period (van der Molen, 2000).

Huizinga and van der Molen (2011) examined developmental change in the speed of responding on choice reaction trials when these trials were preceded by a NoGo trial vs. another choice reaction trial. They observed that choice reactions were significantly delayed when preceded by response inhibition on a NoGo trial relative to response execution on a choice-reaction trial. Moreover, the conflict-adaptation effect was disproportionally larger in young children relative to adolescents and adults. In one important respect, however, the current implementation of the hybrid Choice-reaction/NoGo task was different from the one used by Huizinga and van der Molen (2011). That is, the current task required a demanding conjunction analysis of the direction and color information provided by the arrow stimulus in order to retrieve the appropriate response. The conjunction analysis may impose substantial demands on working memory taking away capacity needed for the configuration of conflict-adaptation measures. Given the protracted course of working-memory development (e.g., Huizinga et al., 2006), we assumed that the absorption of capacity due to the conjunction analysis will disproportionally reduce the capacity young children have available for conflict.
adaptation. Huizinga and van der Molen (2011) interpreted the slowing of choice reactions on trials following a NoGo trial in terms of a reduced readiness to respond. The larger effect observed for young children was then interpreted to suggest that they have greater difficulties in fine-tuning response thresholds following conflict. On the hypothesis that working-memory, conflict-adaptation, and working-memory demands interact (e.g., Gulbinaite, van Rijn, & Cohen, 2014; Weldon, Mushlin, Kim, & Sohn, 2013), we anticipated to observe a pronounced downward trend in the conflict-adaptation effect with advancing age.

**METHOD**

**Participants**
Participants ($N = 66$) were recruited from three age groups; between 7-25 years of age. There were two groups of children; 20 children between 7 and 9-years of age ($M = 8.4$ years; 16 girls) and 24 children between 10 and 12-years of age ($M = 11.3$ years; 13 girls). Finally, a group of 22 young adults between the ages of 18 and 25 ($M = 21.8$ years; 17 females) enrolled in the experiment. The children were selected with the help of their schools. All children had average or above average intelligence based on teachers reports. They received a small present for their participation. The young adults were undergraduate psychology students. They were recruited by flyers and received course credits for their participation. All participants reported to be in good health and had normal or corrected-to-normal vision. Informed consent was obtained from adult participants and primary caregivers of the children. All procedures were approved by the Ethical Review Board of the University.

**Apparatus and stimuli**
All details concerning the apparatus and stimuli were the same as in Experiment 1.

**Design and procedure**
Participants performed a hybrid Choice-reaction/NoGo task. Red arrows pointing to the right required a right-hand response and blue arrows pointing to the left required a left-hand response. In order to elicit a conflict situation, participants should refrain from responding to blue arrows pointing to the right or red arrows pointing to the left. This set-up was counterbalanced across participants. On successful inhibits on NoGo trials, the stimulus was terminated and the RSI started with a delay of 3 s following stimulus onset. The order of arrow directions and colors was pseudo-random. All other design and procedural details were the same as in the previous experiments.
RESULTS AND DISCUSSION

For each participant, trials were sorted for Trial sequence (Choice-Choice vs. NoGo-Choice) and RSI (50 vs. 500 ms). Errors and trials following an error were excluded from RT sorting. Median RTs and error rates (choice errors and commission errors) are presented in Table 3 for each of the above categories.

Error rates

Error rates were low (less than 6%) and did not reveal a negative correlation with RT suggestive of a speed-accuracy tradeoff. Error rates were square-root transformed prior to analyses. Error rates are presented as a function of trial sequence (Choice-Choice, NoGo-Choice, Choice-NoGo and NoGo-NoGo) in Table 3 for each age group and both RSIs.

Choice errors

The rate of choice errors decreased with advancing age; from 7.8%, to 5.6% and 3.4% for young children, older children, and adults, respectively, $F(2, 63) = 45.81, p < .001, \eta^2 p = .59$. Error rates were affected by Trial sequence, $F(1, 63) = 33.23, p < .001, \eta^2 p = .35$, but this effect was qualified by an interaction with Age group, $F(2, 63) = 95.04, p < .001, \eta^2 p = .75$. Adults made somewhat more errors following a NoGo trial (from 2.8 to 4.1 %), $p < .001, \eta^2 p = .94$, whereas young children showed the opposite (from 8.2 to 7.5 %), $p < .001, \eta^2 p = .76$. Error rates of older children were about equal across trial sequences (5.6 %), $p > .9$. RSI did not alter these trends ($ps > .09$).

Commission errors

The rate of commission errors decreased with advancing age (from 9.4%, to 5.6%, and 3.9% for young children, older children, and adults, respectively), $F(2, 63) = 55.19, p < .001, \eta^2 p = .64$. This trend is consistent with previous reports indicating that the ability to stop motor responses on NoGo trials increases when children are growing older (e.g., Jonkman et al., 2003). Error rate was affected by Trial sequence, $F(1, 63) = 24.00, p < .001, \eta^2 p = .28$, but this effect was qualified by an interaction with Age group, $F(2, 63) = 6.19, p < .004, \eta^2 p = .16$. Moreover, the three-way interaction with RSI was also significant, $F(2, 63) = 42.76, p < .001, \eta^2 p = .58$. For the short RSI commission errors tended to decrease for NoGo-NoGo sequences relative to Choice-reaction/NoGo sequences in children while this pattern was opposite for young adults. In contrast, for the long RSI, there was no difference between trial sequences in the proportion of commission errors in adults while the pattern observed for children seems opposite to the pattern.
### Table 3. Mean RT (ms; upper table) and Error Rate (choice and commission %; lower table) for each trial sequence, RSI and age group (Experiment 3).

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Choice Reaction-Choice Reaction</th>
<th>NoGo-Choice Reaction</th>
<th>Choice Reaction-NoGo</th>
<th>NoGo-NoGo</th>
</tr>
</thead>
<tbody>
<tr>
<td>7-9 yrs</td>
<td>RT (ms)</td>
<td>Errors (choice) (%)</td>
<td>Errors (comm.) (%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>RSI-50 ms</td>
<td>RSI-3 s</td>
<td>RSI-500 ms</td>
<td>RSI-3 s</td>
</tr>
<tr>
<td></td>
<td>Choice Reaction</td>
<td>NoGo-Choice Reaction</td>
<td>Choice Reaction-NoGo</td>
<td>NoGo-NoGo</td>
</tr>
<tr>
<td>7-9 yrs</td>
<td>783.31</td>
<td>7.5</td>
<td>8.9</td>
<td>10.1</td>
</tr>
<tr>
<td>10-12 yrs</td>
<td>597.17</td>
<td>5.3</td>
<td>5.9</td>
<td>5.9</td>
</tr>
<tr>
<td>18-25 yrs</td>
<td>443.99</td>
<td>2.5</td>
<td>3.0</td>
<td>2.9</td>
</tr>
</tbody>
</table>

#### Note
- Choice Reaction-Choice Reaction: current Choice Reaction trial preceded by a Choice Reaction trial; NoGo-Choice Reaction: current Choice Reaction trial preceded by a NoGo trial; Choice Reaction-NoGo: current NoGo trial preceded by a Choice Reaction trial; NoGo-NoGo: current NoGo trial preceded by a NoGo trial.
- RSI in Choice-reaction/NoGo task: 50 or 500 ms for Choice Reaction to Choice Reaction or Choice Reaction to NoGo sequences but for sequences starting with NoGo there was an inter-trial interval of 3 s.
associated with the short RSI. That is, the proportion of commission errors tended to increase for NoGo-NoGo sequences relative to Choice-reaction/NoGo sequences.

**Response speed**

The speed of responding increased with advancing age, \( F(2, 63) = 448.33, p < .001, \eta^2_p = .93 \). Adults (\( M = 433 \) ms) responded faster than older (\( M = 643 \) ms) and younger children (\( M = 812 \) ms). Post-hoc analysis indicated that each age group differed significantly from the others (\( ps < .001 \)). Responses were faster for long (\( M = 602 \) ms) compared to short RSIs (\( M = 656 \) ms); \( F(1, 63) = 49.38, p < .001, \eta^2_p = .44 \). This RSI effect was not affected by Age group, \( p > .25 \).

Importantly, the anticipated Trial sequence effect was highly significant, \( F(1, 63) = 102.05, p < .001, \eta^2_p = .62 \). Responses on Choice trials following a NoGo trial were considerably slower than when preceded by a Choice trial (\( M = 674 \) ms and \( M = 584 \) ms, respectively). The Trial sequence effect interacted with Age group, \( F(2, 63) = 8.62, p < .001, \eta^2_p = .22 \). The interaction of the Trial sequence effect and Age group is plotted in Figure 3. It can be seen that the effect observed for children almost triples the effect for adults. However, the interaction did not survive when using average group RT as covariate, \( p > .29 \). Finally, the Trial sequence effect was somewhat larger in the short (\( M = 97 \) ms) compared to long (\( M = 85 \) ms) RSI blocks, but this effect was far from

![Figure 3](image_url)

**Figure 3.** Reaction time difference (ms), including standard error bars, between NoGo-Choice Reaction vs. Choice-Reaction-Choice Reaction trials (i.e., Trial sequence effect) for each age group.
significant, \( p > .53 \). Moreover, the three-way interaction with Age group did not reach significance either, \( p > .61 \).

As in the two previous experiments, we averaged data across the two RSIs and categorized trial sequences in terms of repetitions vs. alternations of arrow direction. The results indicated that, in contrast to predictions based on the repetition priming account, responses on choice trials following a NoGo trial were somewhat shorter rather than longer for repetition (\( M = 663 \) ms) vs. alternation (\( M = 686 \) ms) sequences. Importantly, Age group was not included in the higher-order interaction with Trial sequence and the Repetition vs. Alternation effect, \( p > .07 \).

At this point, it should be noted that the comparison between Choice-Choice sequences vs. NoGo-Choice sequences vis-à-vis RSI is confounded by the long inter-trial interval following NoGo trials. That is, the RSI following a Choice trial was either 50 ms or 500 ms whereas the inter-trial interval following a NoGo trial was 3 s. Thus, it could be argued that the apparently larger modulation effect in children (i.e., the difference in RT between Choice-Choice sequences vs. NoGo sequences) was due to age-related changes in response preparation rather than cognitive control. However, the few results available to date suggest there is little developmental change for the age groups and time intervals relevant to the current analysis (e.g., Adam, Ament, & Hurks, 2011).

In conclusion, the current findings, obtained using a hybrid Choice-reaction/NoGo task, are consistent with the adult literature examining the speed of responding on respond trials that are preceded by either a NoGo trial vs. respond trial. This literature indicates that responses are typically slower on Go trials preceded by a NoGo trial relative to a respond trial (e.g., Gade & Koch, 2005; Hoffmann et al., 2003; Jamadar, Hughes, Fulham, Michie, & Karayanidis, 2010; Kleinsorge & Gajewski, 2004; Rieger & Gauggel, 1999; Rieger et al., 2003; Schuch & Koch, 2003; Verbruggen & Logan, 2008).

**GENERAL DISCUSSION**

This study set out to assess developmental change in conflict adaptation. Within the developmental literature, conflict adaptation is considered to be a manifestation of top-down cognitive control and, given the protracted developmental course of brain mechanisms implicated in top-down cognitive control, it is assumed that with advancing age children are better able to deal with conflict when it arises and to prepare for future conflict (e.g., Iani et al., 2014). Several studies observed conflict adaptation in young children (e.g., Ambrosi et al., 2016; Stins et al., 2007) suggesting that they are already able to effectively respond to conflict and to implement performance adjust-
How do children deal with conflict? The major goal of the present study was to systematically assess developmental change in conflict adaptation. We used a different conflict task in each of the three experiments reported in this study, as the specific implementation of conflict adaptation may depend on the specific conflict elicited by the task (e.g., Egner, 2008; Braem et al., 2014) and, thus, may contribute to the inconsistencies observed in the developmental literature (current review). The leading hypothesis of the study was that the size of the conflict adaptation effect would change with advancing age consistent with the idea that brain mechanisms involved in conflict adaptation are slow to mature. Furthermore, it was assumed that all three experiments would generate a developmental trend, although the pattern of conflict adaptation may differ across experiments depending upon the specific conflict elicited. Comparability across experiments was ensured by using a similar task format—left- vs right-pointing arrows in different colors. In all three experiments, it was examined whether repetition-priming may contribute to the observed developmental trends. This was done because it has been argued that conflict adaptation might result from a repetition of stimulus and response features across trials (e.g., Hommel, Proctor, & Vu, 2004; Mayr et al., 2003). Finally, RSI was manipulated in all three experiments (50 vs. 500 ms, in separate trial blocks). Previously, it had been observed that conflict adaptation was absent for a 50 ms RSI and this finding was taken to suggest that the implementation of the performance adjustments to conflict adaptation requires some time to be implemented (Notebaert et al., 2006). Accordingly, group differences were anticipated to be absent for the 50 ms RSI condition, as 50 ms would be too short for all age groups to effectively put the required performance adjustment into operation.

Conflict adaptation and the Simon task. The current implementation of the Simon task required participants to respond to the color of left- or right-pointing arrows while ignoring the directional information of the arrow. In this version of the Simon task, the conflict is elicited by the location of the required response and the directional information associated by the arrow. Consistent with the literature (Vu & Proctor, 2004), the speed of responding was considerably slower on incongruent trials (with conflicting stimulus and response features) relative to congruent trials (without conflict). This pattern was observed for all three age groups, but the Simon effect was significantly larger in children compared to adults. This finding is consistent with previous developmental
studies of the Simon effect (e.g., Araujo, Mandoske, & White, 2015; Gathercole et al., 2014; Jerger et al., 1999; but see Band et al., 2000).

The size of the Simon effect was reduced considerably on trials following an incongruent relative to a congruent trial. This finding is in line with the adult literature on conflict adaptation using various versions of the Simon task (e.g., Kerns, 2006; Soetens, Maetens, & Zeischka, 2010; Sturmer, Leuthold, Soetens, Schroter, & Sommer, 2002; Duthoo et al., 2014, for a review). Importantly, the reduction of the Simon effect following an incongruent trial was observed for all three age groups. This observation is consistent with previous studies reporting conflict adaptation in children performing on a Simon task (e.g., Ambrosi et al., 2016; Iani et al., 2014). A subsequent analysis, taking the potential contribution of association priming into account, indicated that age-related changes in conflict-adaptation were not altered by the repetition vs. alternation of arrow direction across trials. This observation is similar to the results reported by Waxer and Morton (2011). A secondary analysis controlled for group differences in the speed of responding. This analysis revealed that the developmental trend in the conflict adaptation effect was not disproportional.

In contrast to expectations, the reduction of the Simon effect on trials following an incongruent trial was more pronounced when RSI was 50 ms relative to the 500 ms RSI condition. This pattern was observed for all three age groups. The dual-route model, proposed by Kornblum et al. (1990), may provide a possible interpretation of the apparent annihilation of the conflict adaptation effect in the 50 ms RSI condition. This model assumes that a slow, controlled processing route is activated by task-defined features of the stimulus (i.e., the color of the arrow) connected to a designated response whereas a fast, automatic route is activated by the spatial features of the stimulus (i.e., the direction of the arrow) connected to a response on the basis of pre-existing stimulus-response associations. On incongruent trials, the fast, automatic route has to be suppressed to allow for the execution of the appropriate response along the slow, controlled processing route. Possibly, the inhibition of the fast, automatic route persists into the next trial when RSI is very short. Accordingly, stimulus processing follows the slow, controlled route on all trials, incongruent and congruent, thereby annihilating the Simon effect.

Conflict adaptation and the SRC task. The implementation of the current version of the SRC task was similar to the Simon task, in that participants were asked to respond to colored arrows, but the important difference is that now both the color and direction of the arrow determine the response. Conflict is then elicited when color and direction point to opposite responses. On compatible trials, the color of the arrow indicates that a response is required in the direction of the arrow whereas on incompatible trials the
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Color indicates that the opposite response should be executed. The adult literature indicates that on pure blocks the speed of responding is considerably slower on incompatible than compatible trials (Kornblum et al., 1990), whereas mixing trials may result in the annihilation of the SRC effect (e.g., van Duren & Sanders, 1992). The current results are consistent with the literature in showing that mixing compatibility resulted in the overall elimination of the SRC effect. More specifically, however, the results showed that, consistent with previous studies (e.g., Jennings et al., 2002; Mansfield et al., 2012; but see De Jong, 1995), the typical SRC effect (i.e., slower responses on incompatible relative to compatible trials) seen on trials following a compatible trial turned into its opposite on trials following an incompatible trial. It has been suggested that the reversal of the SRC effect on trials following an incompatible trial results from a preparatory bias for the incompatible mapping (e.g., Jennings et al., 2002). The preparatory bias consists of the suppression of the compatible mapping that has to be released when a compatible, not an incompatible, mapping is called for (De Jong, 1995). This preparatory bias has been interpreted in terms of proactive control; that is, a willful strategy facilitating incompatible mappings (Mansfield et al., 2012).

On the hypothesis that young children are less able or inclined to adopt a proactive strategy in handling cognitive conflict (e.g., Chevalier et al., 2014; Munakata et al., 2012), we anticipated that the pattern of trial-to-trial modulation of SRC on the speed of responding would be less manifest in children than adults. The results were opposite. If anything, trial-to-trial modulation was stronger, not weaker, in children although it should be noted that the differences between age groups lost significance when controlling for basic response speed. The current failure to obtain a disproportional developmental trend in the pattern of sequential SRC effects on the speed of responding may present a challenge to notions that proactive control is a key factor in producing this pattern. A second challenge is presented by the current observation that this pattern is less rather than more manifest for the longest RSI.

The trial-to-trial modulation of the SRC effect was more pronounced for the 50 ms relative to the 500 ms RSI. Similar to the data-pattern observed for the Simon effect, the current SRC pattern is in conflict with notions suggesting that the implementation of control operations following conflict are time consuming (e.g., Notebaert et al., 2006). Indeed, the current findings seem to present a challenge to the idea that the mixing of SRC results in a preparatory bias favoring incompatible mappings. In order to provide an account for the current findings reference can be made to the task-switching literature (for a review, Vandierendonck, Liefooghe, & Verbruggen, 2010). In this literature, comparisons are made between trial sequences repeating a task and trial sequences involving a change from one task to another. Typically, task transitions
involve a cost that is usually greater for the strongest task (e.g., over-learned or well-practiced tasks; e.g., Allport, Styles, & Hsieh, 1994) and costs decrease with increasing RSIs in the absence of foreknowledge (e.g., Sohn & Anderson, 2001). Accordingly, the current data pattern (i.e., stronger mixing costs for compatible relative to incompatible trials and a reduction of mixing costs for the longer RSI) is highly similar to the findings reported in the task-switching literature. Herein, it has been proposed that the task set of the previous trial carries over into the current trial and may facilitate or hinder the implementation of the task set that is required on this trial (e.g., Rogers & Monsell, 1995; for a review Grange & Houghton, 2014).

Conflict adaptation and the hybrid Choice-reaction/NoGo task. The current hybrid Choice-reaction/NoGo task required participants to perform a conjunction analysis involving the color and direction of the arrow stimulus. Thus, they were required to respond in the direction of the arrow, but only when the arrow was of a certain color, while they had to inhibit their response when the arrow was of a different color. The current findings indicated that, in spite of the requirement to perform a conjunction analysis, all age groups performed the task well, even the youngest children. Overall, both the choice and commission error rates remained below 10%. The proportion of commission errors decreased with advancing age, consistent with notions suggesting that the ability to inhibit speeded responses increases when children are getting older (e.g., Casey et al., 1997; Cragg & Nation, 2008; Jonkman et al., 2003).

RTs revealed a pronounced delay when choice-reaction trials were preceded by a NoGo trial relative to a choice-reaction trial. This finding is consistent with the Go/NoGo literature showing that responses on a Go trial are typically delayed when the Go trial follows response inhibition on a NoGo trial (e.g., Gade & Koch, 2005; Hoffmann et al., 2003; Jamadar et al., 2010; Kleinsorge & Gajewski, 2004; Rieger & Gauggel, 1999; Rieger et al., 2003; Schuch & Koch, 2003; Verbruggen & Logan, 2008). It should be noted, however, that for the current data, a straightforward comparison between the speed of responding on choice-reaction trials preceded by another choice-reaction trial vs. choice-reaction trials preceded by a NoGo trial is complicated by a design issue. That is, RSI was either 50 ms or 500 ms for choice-reaction to choice-reaction sequences whereas the time-interval between a NoGo stimulus and the subsequent choice-reaction stimulus was 3 s. Thus, the delay observed for responses on Go trials preceded by a NoGo trial could be due to a longer wait reducing response readiness, to more caution, also reducing response readiness, or to a mixture of both. However, attributing the substantial delay in responding to a longer wait does not seem plausible in view of findings reported by Näätänen et al. (1974). These authors examined the effect of foreperiod (i.e., the interval between a warning and a response signal) on the speed
of responding using various delays (.25, .5, 1, 2, and 4 s). Their results showed that the speed of responding increased with a lengthening of the foreperiod. A similar pattern has been reported by Adam and colleagues, who examined the speed of responding to time-intervals between .2 and 2 s (Adam et al., 2011). Moreover, it was observed that children (age between 9 and 13 years) showed the same trend. In brief, attributing the delay in responding on a choice-reaction trial preceded by a NoGo trial to cognitive control is more likely than an interpretation in terms of reduced response readiness associated with a longer wait.

The current findings yielded a 40 ms delay in the speed of responding on choice-reaction trials preceded by NoGo trials versus the speed of responding on choice-reaction trials preceded by another choice-reaction trial. This sizeable difference basically tripled in children. There are few studies examining developmental change in the speed of responding following response inhibition on the immediately preceding trial. Consistent with the present findings, these studies revealed a developmental decrease in the delay of responding on Go trials preceded by a NoGo trial. Huizinga and van der Molen (2011) examined switching from a NoGo trial to a choice-reaction trial and observed a pronounced delay on choice-reaction trials following a NoGo trial for adults (about 60 ms) and this delay almost doubled for 11-year olds and increased close to 160 ms for 7-year olds. In contrast to the present findings, however, the developmental trend survived when controlling for age-group differences in basic respond speed. Huizinga and van der Molen (2011) interpreted their data to suggest that the readiness to respond decreases following the encounter of a NoGo trial (see also Jamadar et al., 2010) resulting in an increase in response thresholds. The more pronounced delay in the speed of responding observed in children is then explained by assuming that adults are better able to fine-tune their response thresholds (cf. Huizinga & van der Molen, 2011; p. 499).

**CONCLUSION**

The current study yielded evidence for developmental change in the sequential modulation of conflict effects on three tasks; a Simon task, a mixed SRC task and a hybrid Choice-reaction/NoGo task. In broad outline, the current pattern of results contributes to an emerging literature demonstrating that sequential modulation of conflict effects can be observed already in young children (e.g., Ambrosi et al., 2016; Iani et al., 2014; Larson et al., 2012; Nieuwenhuis et al., 2006; Stins et al., 2007; Wilk & Morton, 2012; but see Waxer & Morton, 2011).

The observation of conflict-modulation in young children does not seem to square with interpretations of conflict adaptation in terms of top-down control. More specifically,
Gratton et al. (1992) argued that an encounter with a conflict trial would increase the expectation that another conflict trial follows and this expectation initiates top-down control adjustments reducing the potential influence of conflicting information. Another perspective, proposed by Botvinick et al. (2001), assumed a cognitive mechanism enabling the detection of conflict when it occurs resulting into the signaling of control mechanisms involved in top-down adjustments to reduce the effects of potential conflict on the immediately subsequent trial. Cognitive neuroscience studies revealed that the anterior cingulate cortex (ACC) responds to conflict signaling other brain areas, including the prefrontal cortex (PFC), to reduce conflict and improve performance (e.g., Kerns, 2006). Developmental cognitive neuroscience amassed evidence to suggest that both the ACC and PFC follow a protracted maturational course (for a review Crone & Steinbeis, 2017). Collectively, the behavioral and cognitive neuroscience literatures suggest that manifestations of conflict adaptation that have been observed in young children are not likely to originate from top-down cognitive control strategies. In this regard, the suggestion, put forward by Ambrosi et al. (2016), that even 5-to-7 year olds are able to coordinate reactive and proactive control strategies does not seem to be very plausible.

The present findings showed a developmental decrease in the trial-by-trial modulation of the Simon effect, a more pronounced reversal of the SRC effect following an incompatible trial for younger children and a downward age-related reduction in the speed of responding following a NoGo trial. Importantly, none of these age-related trends survived when controlling for age-group differences in basic speed. This pattern of results is most compatible with the findings reported previously by Wilk and Morton (2012). These authors investigated age-related changes in conflict adaptation by manipulating the probability of compatible vs. incompatible trials in mixed compatibility trial blocks. Consistent with previous studies (e.g., Gratton et al., 1992; Logan & Zbrodoff, 1979), it was observed that increasing the probability of incompatible trials greatly reduced the compatibility effect. Importantly, the size of this conflict-adaptation effect was comparable across ages from 9 to 34 years. In contrast, the neural activation pattern associated with conflict adaptation revealed substantial changes with advancing age. More specifically, it was observed that activity in the anterior insula, anterior cingulate, lateral prefrontal cortex and intraparietal sulcus was associated with conflict-adjustments in older but not younger participants. Consequently, there is an apparent dissociation between the behavioral and neural manifestations of developmental change in conflict-adaptation. Wilk and Morton (2012) raised the possibility that children and adults may entertain different control modes in achieving the same goal or, alternatively, that age-related changes in structural or functional connectivity
between brain regions might have contributed to different neural activation patterns for children and adults.

The current, albeit statistically nonsignificant, downward trend in the conflict-adaptation effect is most readily explained by assuming that contextual cues associated with the probability of conflict may automatically retrieve from memory the control settings that are compatible with the current task demands (e.g., Crump & Logan, 2010). Thus, when conflict is encountered the control settings that are then used by the system to efficiently ensure the resolution of conflict are then carried over to the next trial when the demands of this trial are similar to the previous one. It should be noted that this view does preclude but goes beyond simple associative notions of trial-by-trial conflict adaptation (e.g., Egner, 2014). Indeed, the current results revealed that response priming altered the sequential effects, in particular on the SRC task. Importantly, however, such priming effects did not interact with age. Furthermore, results indicated that sequential modulation was present even for trial sequences that did not involve response repetitions. Collectively, the sequential modulation patterns observed in the current study indicate that conflict adaptation observed for the current tasks is not just a manifestation of associative mechanisms (see also Ullsperger et al., 2005).

In sum, the current age-related downward trend in conflict adaptation is difficult to reconcile with developmental changes in strategic top-down cognitive control. On the other hand, the current findings cannot be explained by resorting to simple associative views of trial-to-trial conflict adaptation. The current interpretation opted for the middle ground proposed by Egner (2014) assuming that, once the task set involved in the resolution of conflict has been established, it can be automatically triggered and implemented by the appropriate contextual information (see also Egner, 2008; Hubbard, Kuhns, Schafer, & Mayr, 2016). The finding that the age-related downward trend in the size of the conflict adaptation effect did not survive when controlling for age-group differences basic response speed may then suggest that, when the appropriate control settings have been retrieved from memory, the implementation and workings of the mechanisms needed to resolve conflict become more efficient with advancing age. In this regard, developmental change in those mechanisms follows the general path of the information processing system towards greater efficiency (e.g., Cerella & Hale, 1994).