Congruency Sequence Effects in 9- to 10-Year-Old Children and Adults

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Abstract

The congruency sequence effect refers to the ability of individuals to flexibly adapt to the current environment based on conflict information from the previous context. This study selected children aged 9–10 years and adults aged 18–25 years as participants, and employed a color-word Stroop task and a mixed Stroop-Flanker task. After controlling for repetition priming effects, age differences in the congruency sequence effect across different tasks were examined. The results revealed that both children and adults exhibited significant congruency sequence effects across different tasks, with no significant difference in the magnitude of these effects. These findings indicate that the conflict adaptation process involves higher-level processing, and that children aged 9–10 already possess more generalized conflict adaptation abilities similar to those of adults.

Full Text

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Abstract

Congruency sequence effects (CSEs) reflect an individual' s ability to flexibly adapt to current environments based on conflict information from previous contexts. This study examined age-related differences in CSEs across different tasks by testing 9- to 10-year-old children and 18- to 25-year-old adults using a color-word Stroop task and a mixed Stroop-Flanker task, while controlling for repetition priming effects. The results revealed significant CSEs in both children and adults across different tasks, with no significant differences in the magnitude of these effects between age groups. These findings suggest that conflict adaptation involves higher-order processing mechanisms and that 9- to 10-year-old children have already developed generalized conflict adaptation abilities comparable to those of adults.

Keywords: cognitive adaptation; congruency sequence effect; color-word Stroop task; Flanker task
Classification Number: B842

Introduction

Executive functions (EFs) represent higher-order cognitive processes that play crucial roles in social life (Cao et al., 2013; Lustig, Hasher, & Tonev, 2006; Titz & Karbach, 2014). In constantly changing environments, EFs effectively regulate adaptive behaviors to achieve current goals (Diamond, 2013). Among the various subcomponents of EF, interference control refers to the ability to regulate attention by inhibiting irrelevant stimuli or stimulus features to produce correct responses (Miyake, Friedman, Emerson, Witzki, & Howerter, 2000). Classic paradigms for studying interference control include the color-word Stroop task (MacLeod, 1991) and the Flanker task (Eriksen & Eriksen, 1974). Both tasks require participants to inhibit non-target stimuli when target and non-target stimuli are presented simultaneously. Congruent trials occur when non-target stimuli elicit the same response as target stimuli, whereas incongruent trials occur when they elicit different responses. During incongruent trials, individuals must inhibit attention to non-target (conflict) stimuli and suppress corresponding behavioral responses. Extensive research has demonstrated that reaction times (RTs) are faster and accuracy higher in congruent compared to incongruent trials (Egner & Hirsch, 2005; Goldfarb, Aisenberg, & Henik, 2011; Stins, Polderman, Boomsma, & De Geus, 2007). Consequently, researchers define the difference between incongruent and congruent trials in RT and accuracy as the congruency effect, which measures the magnitude of interference control.

Beyond measuring interference control through congruency effects, another approach reflects the flexibility and adaptability of interference control abilities. Rapid trial-to-trial adaptation in tasks examining inhibitory control can be observed in the form of congruency sequence effects (CSEs), also known as conflict adaptation effects or Gratton effects. First discovered by Gratton et al. (1992) using the Flanker task, CSEs have subsequently been observed in other inhibitory control tasks (Kerns, 2006; Larson, Clawson, Clayson, & South, 2012; Larson, Kaufman, & Perlstein, 2009). CSEs manifest as significantly smaller congruency effects following incongruent trials compared to those following congruent trials (Duthoo et al., 2014b). Specifically, RTs are faster and accuracy higher in incongruent trials preceded by incongruent trials (iI) compared to incongruent trials preceded by congruent trials (cI). Alternatively, RTs are faster and accuracy higher in congruent trials preceded by congruent trials (cC) compared to congruent trials preceded by incongruent trials (iC). Both patterns may also occur simultaneously (Lamers & Roelofs, 2011).

At least three theoretical accounts have been proposed to explain CSEs (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Gratton et al., 1992; Mayr, Awh, & Laury, 2003). The first is conflict monitoring theory (Botvinick et al., 2001), which posits that when interference information appears, the anterior cingulate cortex (ACC) detects the conflict signal and subsequently activates the dorsolateral prefrontal cortex (DLPFC) to enhance top-down cognitive control and adjust cognitive resources. When the previous trial is incongruent, relevant brain regions remain in a higher activation state, resulting in greater cognitive control. Consequently, the cognitive system is in a proactive preparatory state during the current incongruent trial, enabling more effective conflict monitoring and control. The second theoretical perspective is the repetition-expectancy account (Gratton et al., 1992), which suggests that participants generally expect two consecutive trials to be of the same type (both congruent or both incongruent). In the Flanker task, following an incongruent trial, participants expect the next trial to also be incongruent, narrowing attentional focus to the central stimulus. Conversely, following a congruent trial, participants expect another congruent trial, broadening attentional scope. According to this theory, these different expectations combine to produce CSEs. The third explanation is based on the concept of low-level repetition effects (Mayr et al., 2003), incorporating feature-integration or feature-priming perspectives (Hommel, Proctor, & Vu, 2004). This account argues that no cognitive adaptation process exists and therefore no ACC or DLPFC involvement is required. Instead, it emphasizes that in standard Stroop and Flanker tasks, the cognitive system integrates stimulus features with response features and stores them in episodic memory when stimuli appear. When stimulus features repeat in the next trial, they activate the integrated pattern from the previous trial, resulting in shorter RTs and producing an adaptation effect (Nieuwenhuis et al., 2006). According to feature-integration theory, differences in RT arise because the simultaneous occurrence of stimulus and response automatically triggers a brief stimulus-response (S-R) association. This associative pattern indicates that when one element (S or R) of the association is reactivated, the other element (R or S) is also activated.

Regarding age differences in CSEs, most studies have examined adult populations (Duthoo et al., 2014b; Freitas, Bahar, Yang, & Banai, 2007; Funes, Lupiáñez, & Humphreys, 2010; Jiménez & Méndez, 2013). Relatively few studies have investigated CSEs in children and adolescents using standard interference control tasks, and these studies have found that CSEs emerge as early as age 5 (Ambrosi, Lemaire, & Blaye, 2016; Cragg, 2016; Erb, Moher, Song, & Sobel, 2018; Iani, Stella, & Rubichi, 2014; Larson et al., 2012; Nieuwenhuis et al., 2006; Stins et al., 2007). However, some of these studies did not effectively control for the possibility that CSEs were driven by low-level processing mechanisms (i.e., the feature-integration account) (Ambrosi et al., 2016; Iani et al., 2014; Stins et al., 2007). Additionally, some studies did not directly compare different age groups within the same experiment (Ambrosi et al., 2016; Stins et al., 2007), while others failed to find stable CSEs across all interference control tasks. For example, Ambrosi et al. (2016) observed CSEs in Stroop and Simon tasks but not in the Flanker task. Therefore, some studies have employed experimental designs or post-hoc trial separation to exclude repetition priming effects (Erb et al., 2018; Larson et al., 2012; Nieuwenhuis et al., 2006). In summary, whether children exhibit the same adaptive abilities and patterns of cognitive control as adults remains an open question requiring further investigation.

CSEs are based on individuals' inhibitory control abilities. Research indicates that ages 9.6 to 11.5 represent a period of rapid inhibitory control development (Brocki & Bohlin, 2004). Furthermore, Zhao and Jia (2018) used a modified Stroop task to train interference control in children with a mean age of 10.48 years, finding that children at this age stage showed greater plasticity in inhibitory control compared to adults. Accordingly, ages 9 to 10 may also represent a critical period for conflict adaptation development. Moreover, 9- to 10-year-old children show comparable behavioral performance on interference control tasks (MacLeod, 1991; Rueda et al., 2004), though current research findings remain inconsistent (Larson et al., 2012; Waxer & Morton, 2011). For instance, Waxer and Morton (2011) examined CSEs across different age groups and found that 9- to 11-year-old children did not show significant CSEs. In contrast, Larson et al. (2012) tested 21 children with a mean age of 9.7 years and 26 adults using the Stroop task and found that children exhibited significant CSEs that did not differ significantly from those of adults. Research suggests that the maturation of the anterior cingulate cortex (ACC) related to cognitive control does not occur until early adulthood (Adleman et al., 2002), and prefrontal cortex (PFC) maturation continues at least through adolescence (Luna & Sweeney, 2004). Consequently, the brain structures and functions involved in inhibitory control tasks are not yet fully mature in 9- to 10-year-old children (Luna et al., 2004), and children' s adult-like behavioral performance may be achieved through activation of alternative neural circuits (Wilk & Morton, 2012).

As noted above, the extent to which children can exhibit flexible adaptation abilities similar to adults requires more thorough evaluation. Therefore, this study tested 9- to 10-year-old children and 18- to 25-year-old adults to investigate age differences in CSEs. The study included two experimental tasks. Task 1 was a standard two-choice color-word Stroop task analyzing only trials with response changes to control for low-level processing effects. Based on previous research (Larson et al., 2012), we predicted that children would show slower RTs and higher error rates than adult participants. Our primary research question, however, was whether children would exhibit CSEs similar to those of adults. Task 2 employed a mixed design with both Stroop and Flanker trials to further exclude potential low-level processing influences. Cross-task CSEs provide more compelling evidence for cognitive control adaptation because the previous and current trials involve completely different stimuli. Compared to the single-task condition (Task 1), the mixed Flanker-Stroop task is relatively more difficult, thereby increasing cognitive control demands and requiring greater cognitive resources. Research has demonstrated cross-task CSEs in adult participants under certain conditions (Braem et al., 2014). However, given that relevant brain regions are not yet fully developed in children (Adleman et al., 2002; Luna & Sweeney, 2004), we predicted that children might be unable to effectively adjust cognitive resources to adapt to conflict environments in cross-task conditions. Consequently, age differences in cognitive control abilities might be more pronounced (Benikos, Johnstone, & Roodenrys, 2013; Kray, Karbach, & Blaye, 2012).

Method

Participants

Thirty-three university students aged 18 to 25 years (19 male) voluntarily participated in the experiment, with a mean age of 20.6 years (SD = 0.33). Thirty-four 9- to 10-year-old children (16 male) from an elementary school also participated, with a mean age of 9.5 years (SD = 0.09). Based on standard psychological assessments from the school, none of the children had a history of psychiatric or neurological disorders. Adult participants provided informed consent, and guardians of child participants provided informed consent on their behalf. All participants were Han Chinese, right-handed, had normal or corrected-to-normal vision, and no color blindness. Participants received compensation after completing the experiment.

Tasks and Stimuli

The experimental tasks were programmed using E-Prime software, with stimuli presented on a 17-inch computer monitor. Participants were seated approximately 60 cm from the screen. In the Stroop task (Task 1), stimuli consisted of the Chinese characters “红” (red) and “绿” (green) printed in colored ink. Congruent trials occurred when the character “红” was printed in red ink, while incongruent trials occurred when “红” was printed in green ink. Similarly, the character “绿” printed in red was incongruent, and “绿” printed in green was congruent. Task 2 included both the “红” and “绿” characters from Task 1 and arrow Flanker stimuli. In the Flanker task, stimuli consisted of five arrows. Congruent trials occurred when all five arrows pointed in the same direction (»»> or ««<), while incongruent trials occurred when the middle arrow pointed in the opposite direction from the surrounding arrows (»<» or «>«). All tasks required participants to respond using their left index finger to press the “F” key and their right index finger to press the “J” key.

Design and Procedure

The experiment employed a 2 (previous trial congruency: congruent c, incongruent i) × 2 (current trial congruency: congruent C, incongruent I) × 2 (age group: children, adults) mixed design, with previous and current trial congruency as within-subjects factors and age group as a between-subjects factor. The experiment was conducted over two consecutive days. On the first day, participants completed Task 1 (the color-word Stroop task). To avoid practice and fatigue effects, participants were instructed to return home and rest before completing Task 2 (the mixed Flanker-Stroop task) on the second day.

The experimental procedure was as follows: A black fixation cross "+" first appeared on a gray screen for 500 ms, followed by a random blank interval of 300-500 ms. The stimulus then appeared for 1500 ms and disappeared immediately after the participant responded, followed by a 1000 ms blank interval before the next trial began. In Task 1 (see Figure 1 [Figure 1: see original paper] left), participants were always instructed to respond to the ink color. They pressed the "F" key with their left index finger if the ink was red and the "J" key with their right index finger if the ink was green. In Task 2 (see Figure 1 right), when arrows appeared, participants were instructed to respond to the direction of the middle arrow while ignoring the surrounding arrows. They pressed the "F" key if the middle arrow pointed left and the "J" key if it pointed right. When color words appeared, the instructions were identical to Task 1: respond to the ink color by pressing "F" for red and "J" for green. Participants were instructed to respond as quickly and accurately as possible.

The experimental program consisted of one practice block and four experimental blocks. In the practice block, participants had to achieve 85% accuracy to proceed to the formal experiment. In Task 1, the practice block included 32 congruent and 32 incongruent trials, while the formal experiment comprised 256 trials with a pseudorandom presentation order. Participants could control the duration of rest periods between blocks, and the entire task lasted approximately 15 minutes. Task 2 mixed Stroop and Flanker stimuli, with the practice block containing 24 trials (equal proportions of congruent and incongruent trials). After achieving 85% accuracy in practice, participants proceeded to the formal experiment, which consisted of four blocks of 64 trials each (256 total trials). Each block included four Stroop stimuli and four Flanker stimuli. The design enforced strict task switching to minimize task-set related influences and enhance adjustment to changing cognitive demands (Wilk, Ezekiel, & Morton, 2012). Specifically, the first four trials alternated between tasks in either Stroop→Flanker→Stroop→Stroop (SFSS) or Flanker→Stroop→Flanker→Flanker (FSFF) sequences. Subsequent trials continued this pattern of task switching. Across the entire task, both Stroop→Flanker and Flanker→Stroop transition trials included equal numbers of cC, cI, iC, and iI trial types. Participants could rest between blocks, and the entire task required approximately 15 minutes to complete.

Data Analysis

For Task 1, repeated measures ANOVAs were conducted on RTs and accuracy rates with age group (children, adults) as a between-subjects factor and previous trial congruency (congruent, incongruent) and current trial congruency (congruent, incongruent) as within-subjects factors. In the RT analysis, error trials, trials following errors, and trials with response repetitions were excluded. The latter exclusion criterion controlled for repetition effects, resulting in the removal of 32.2% of trials. However, analyses using all data (including repetition trials) showed the same pattern of results. The primary focus was on the interaction between previous and current trial congruency, or the three-way interaction between age group, previous trial congruency, and current trial congruency. When these interactions were significant, follow-up analyses compared congruency effects after congruent trials (cC vs. cI) and after incongruent trials (iC vs. iI), as well as comparing cC versus iC and cI versus iI trials to clarify the source of reduced congruency effects.

For Task 2, data from one adult participant were lost during collection and excluded from analysis. Task 2 focused on cross-task transitions, with RTs and accuracy analyzed using a repeated measures ANOVA with age group, transition type (Stroop→Flanker vs. Flanker→Stroop), previous trial congruency, and current trial congruency as factors. Error trials and trials following errors were excluded from RT analyses. Additionally, to directly compare the magnitude of conflict adaptation effects between adults and children across both tasks, we computed difference scores for RT and accuracy. For RT data, difference scores were calculated as (RTcI -RTcC) -(RTiI -RTiC) (Nieuwenhuis et al., 2006). For accuracy, difference scores were calculated as (ACCcC -ACCcI) -(ACCiC -ACCiI), with larger values indicating stronger cognitive adaptation abilities. All analyses used a p-value of < .05 as the criterion for statistical significance and ^{2} as the measure of effect size.

Results

Task 1 Results

The results for RT and accuracy are presented in Figure 2 [Figure 2: see original paper] and Table 1 . The ANOVA on RTs revealed a significant main effect of age group, $F(1, 65) = 35.28$, $p < 0.001$, $p^2 = 0.35$, with adults responding significantly faster than children. The main effect of current trial congruency was also significant, $F(1, 65) = 64.05$, $p < 0.001$, $p^2 = 0.50$, with faster RTs on congruent than incongruent trials. Critically, the interaction between previous and current trial congruency was significant. Follow-up analyses revealed a significant congruency effect after congruent trials (cC vs. cI), $F(1, 66) = 133.41$, $p < 0.001$, $p^2 = 0.67$, and also after incongruent trials (iC vs. iI), $F(1, 66) = 10.19$, $p = 0.002$, $p^2 = 0.13$, though responses were faster on current incongruent than congruent trials. RTs on cC trials were significantly faster than on iC trials, $F(1, 66) = 62.41$, $p < 0.001$, $p^2 = 0.49$, and RTs on cI trials were significantly slower than on iI trials, $F(1, 66) = 64.83$, $p < 0.001$, $p^2 = 0.50$, indicating clear CSEs. However, adults ($M = 77.72$ ms, $SD = 61.88$) and children ($M = 109.78$, $SD = 86.73$) did not differ significantly in CSE magnitude (difference scores), $F(1, 65) = 3.02$, $p = 0.09$, $p^2 = 0.04$.

The analysis of accuracy revealed a significant main effect of age group, $F(1, 65) = 34.44$, $p < 0.001$, $p^2 = 0.35$, with adults showing higher accuracy than children. The interaction between previous and current trial congruency was significant. Further analyses showed a significant congruency effect after congruent trials (cC vs. cI), $F(1, 66) = 63.50$, $p < 0.001$, $p^2 = 0.49$, but not after incongruent trials (iC vs. iI), $F(1, 66) = 0.55$, $p = 0.46$, $p^2 = 0.01$, again indicating CSEs. Accuracy on iI trials was significantly higher than on cI trials, $F(1, 66) = 52.66$, $p < 0.001$, $p^2 = 0.44$, while accuracy did not differ between cC and iC trials, $F < 1$. Adults ($M = 0.08$, $SD = 0.09$) and children ($M = 0.09$, $SD = 0.11$) did not differ significantly in CSE magnitude (difference scores), $F < 1$.

Task 2 Results

The results for RT and accuracy are presented in Figure 3 [Figure 3: see original paper] and Table 1. As shown in the upper panel of Figure 3, both children and adults showed similar patterns in RT data, with congruency effects slightly reduced following incongruent compared to congruent trials, likely due to faster RTs on cC than iC trials. The ANOVA on RTs with age group, transition type (Stroop→Flanker vs. Flanker→Stroop), previous trial congruency, and current trial congruency revealed a significant interaction between previous and current trial congruency. The congruency effect was significant after congruent trials (cC vs. cI), $F(1, 65) = 185.70$, $p < 0.001$, $p^2 = 0.74$, and also after incongruent trials (iC vs. iI), $F(1, 65) = 123.70$, $p < 0.001$, $p^2 = 0.66$. RTs on cC trials were significantly faster than on iC trials, $F(1, 65) = 36.94$, $p < 0.001$, $p^2 = 0.36$; however, RTs did not differ between iI and cI trials, $F < 1$. CSE magnitude did not differ significantly between age groups or transition types. For Stroop→Flanker transitions, adults ($M = 32.02$ ms, $SD = 52.47$) and children ($M = 14.23$ ms, $SD = 75.21$) did not differ significantly, $p = 0.27$. For Flanker→Stroop transitions, adults ($M = 28.34$ ms, $SD = 59.80$) and children ($M = 48.86$ ms, $SD = 95.17$) also did not differ significantly, $p = 0.30$. Detailed results for other main effects and interactions are presented in Table 1.

As shown in the lower panel of Figure 3, children and adults showed similar trends in accuracy, with congruency effects reduced following incongruent compared to congruent trials. The ANOVA revealed a significant main effect of transition type, $F(1, 64) = 77.27$, $p < 0.001$, $p^2 = 0.55$, with higher accuracy in Stroop→Flanker than Flanker→Stroop transitions, indicating better performance on Flanker than Stroop stimuli. The interaction between previous and current trial congruency was significant. Simple effects analyses revealed a significant congruency effect after congruent trials (cC vs. cI), $F(1, 65) = 57.09$, $p < 0.001$, $p^2 = 0.47$, and after incongruent trials (iC vs. iI), $F(1, 65) = 8.97$, $p = 0.004$, $p^2 = 0.12$. Accuracy on cC trials was significantly higher than on iC trials, $F(1, 65) = 9.76$, $p = 0.003$, $p^2 = 0.13$, and accuracy on iI trials was significantly higher than on cI trials, $F(1, 65) = 6.04$, $p = 0.02$, $p^2 = 0.09$. CSE magnitude did not differ significantly between age groups or transition types.

For Stroop→Flanker transitions, adults (M = 0.04, SD = 0.07) and children (M = 0.06, SD = 0.18) did not differ significantly, p = 0.61. For Flanker→Stroop transitions, adults (M = 0.04, SD = 0.14) and children (M = 0.08, SD = 0.21) also did not differ significantly, p = 0.35.

Discussion

In Task 1 (the Stroop task), both age groups showed similar behavioral patterns and comparable CSE difference scores, with congruency effects significantly reduced following incongruent compared to congruent trials. For RT data, this reduction in congruency effects resulted from faster responses on cC trials compared to iC trials, as well as faster responses on iI trials compared to cI trials. For accuracy analyses, the reduction stemmed from significantly higher accuracy on iI than cI trials in both age groups. In Task 2 (the mixed Stroop-Flanker task), both age groups again showed similar CSE patterns and difference scores in both Stroop→Flanker and Flanker→Stroop transitions. Specifically, RT analyses revealed that all participants responded significantly faster on cC than iC trials, while accuracy analyses showed that accuracy was significantly higher on cC than iC trials and on iI than cI trials.

These Task 1 results are consistent with Larson et al. (2012), who used a three-color Stroop task. Although we found significant age differences in overall RT and accuracy, both children and adults showed significant CSEs across both tasks. Moreover, by excluding all trials involving response repetitions from our analyses, we eliminated the influence of feature-integration or feature-priming effects, ruling out these accounts of CSEs (Hommel, Proctor, & Vu, 2004; Nieuwenhuis et al., 2006). Therefore, the CSEs observed in this study reflect higher-order cognitive adaptation processes rather than lower-level processing induced by response repetition.

Task 2 excluded simple feature-priming effects through experimental design. Under these conditions, children and adults again showed similar CSEs, although the mean CSE difference scores were relatively smaller in Task 2 than in Task 1 for both groups. This indicates that despite potential age differences in brain structures underlying conflict adaptation, the results provide evidence for adaptive cognitive control in children that generalizes across tasks. Both tasks eliminated complete stimulus feature repetition through different approaches, thereby refuting feature-integration or feature-priming explanations. Our findings largely support conflict monitoring theory. According to this account, the significantly faster RTs and higher accuracy on iI compared to cI trials may reflect continuous conflict monitoring and attentional resource adjustment when encountering conflict information, facilitating adaptation to subsequent conflict trials. Additionally, because tasks examining CSEs inevitably include consecutive congruent or incongruent trials, the repetition-expectancy account cannot be completely ruled out. Neurophysiological research suggests neural overlap between adaptation processes based on conflict monitoring theory and those based on repetition-expectancy theory (Duthoo et al., 2014b). Therefore, during conflict adaptation, expectations about trial type and top-down cognitive control may work together to help individuals effectively adapt to conflict environments.

The RT analysis for Task 2 indicated that the interaction between previous and current trial congruency was not moderated by transition type (Stroop→Flanker vs. Flanker→Stroop). However, Figure 3 (upper panel) suggests differences between the two transition types. Specifically, for Stroop→Flanker transitions, CSEs appeared to result solely from significantly faster RTs on cC than iC trials, possibly reflecting attentional scope broadening. In contrast, for Flanker→Stroop transitions, CSEs resulted from both significantly faster RTs on cC than iC trials (attentional scope broadening) and significantly faster RTs on iI than cI trials (attentional focusing or narrowing). These findings are consistent with Freitas et al. (2007, Experiment 2), which tested cross-task CSEs in university students who verbally reported ink colors and arrow directions. Thus, the pattern of CSEs was clearer in Flanker→Stroop than in Stroop→Flanker transitions.

In summary, by manipulating experimental design and conducting post-hoc analyses, this study excluded low-level repetition effects and obtained purer measures of CSEs. Both 9- to 10-year-old children and adults showed significant CSEs under single-task and dual-task conditions, providing behavioral evidence for the development of cognitive control adaptation capacities at this age stage. The study has several limitations. First, the experiment used a fixed task order, with all participants completing Task 1 before Task 2. This arrangement was necessary because we wanted to first establish children’ s CSEs (Larson et al., 2012), but it may have introduced practice effects in Task 2. Second, previous research training response inhibition and interference control in 10- to 12-year-old children found greater plasticity compared to adults (Zhao, Chen, & Maes, 2018; Zhao & Jia, 2018). Future studies could consider training children’ s conflict adaptation abilities to enhance their capacity to process conflict information and flexibly adapt to changing environments. Finally, although brain regions in 9- to 10-year-old children (such as ACC and PFC) are relatively immature, their behavioral performance nearly reached adult levels, providing evidence and support for future neurophysiological research. Larson et al. (2012) used EEG to demonstrate similar SP amplitude changes (a component related to conflict resolution) in children and adults during conflict adaptation. Waxer and Morton (2011) used EEG source analysis to show reduced ACC activity in adults and adolescents on iI compared to cI trials, but not in children. Wilk and Morton (2012) used fMRI to examine brain activity during conflict adaptation in individuals aged 9 to 32 years, finding that despite similar behavioral performance across age groups, older participants showed stronger activation in the anterior cingulate cortex, anterior insula, lateral prefrontal cortex, and intraparietal sulcus. Therefore, future studies should use multiple techniques to investigate whether conflict adaptation in 9- to 10-year-old children involves broader brain regions and to further clarify the nature of CSEs and their developmental differences.

Conclusion

This study tested 9- to 10-year-old children and adults using a single-task color-word Stroop task and a mixed Stroop-Flanker task. By controlling for repetition priming effects, we found that 9- to 10-year-old children exhibited CSEs similar to those of adults in both tasks. These results indicate that conflict adaptation involves higher-order processing mechanisms and that 9- to 10-year-old children have already developed generalized conflict adaptation abilities.

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