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Predictability and context determine differences in conflict monitoring between adolescence and adulthood

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HIGHLIGHTS

- Contextual effects on conflict monitoring in adolescence and adulthood are analyzed.
- Context and predictability both differentially affect performance.
- In certain conditions, adolescents show better performance than adults.
- The systems neurophysiology of the processes is analyzed.

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ABSTRACT

The ability to link contextual information to actions is an important aspect of conflict monitoring and response selection. These mechanisms depend on medial prefrontal networks. Although these areas undergo a protracted development from adolescence to adulthood, it has remained elusive how the influence of contextual information on conflict monitoring is modulated between adolescence and adulthood. Using event-related potentials (ERPs) and source localization techniques we show that the ability to link contextual information to actions is altered and that the predictability of upcoming events is an important factor to consider in this context. In adolescents, conflict monitoring functions are not as much modulated by predictability factors as in adults. It seems that adults exhibit a stronger anticipation of upcoming events than adolescents. This results in disadvantages for adults when the upcoming context is not predictable. In adolescents, problems to predict upcoming events therefore turn out to be beneficial. Two cognitive-neurophysiological factors are important for this: The first factor is related to altered conflict monitoring functions associated with modulations of neural activity in the medial frontal cortex. The second factor is related to altered perceptual processing of target stimuli associated with modulations of neural activity in parieto-occipital areas.

1. Introduction

In the last decade, mechanisms of response selection and action control have received much attention in cognitive neuroscience. For these processes, it has consistently been shown that the medial frontal cortex including the anterior cingulate cortex (ACC), the supplementary motor area (SMA), and the pre-supplementary motor area (pre-SMA) play an important role (e.g., [4,6,36,37,43]. These structures are well-known to show a protracted development in children and adolescents (e.g., [13,20,21,23,49]. Consequently, a vast amount of research has been conducted to examine developmental changes in response selection and conflict monitoring functions between childhood and adulthood using fMRI or EEG measures, showing increasing conflict monitoring performance with increasing age (e.g., [1,7,15,27,35,41,45]. However, an important aspect of conflict monitoring and response selection is the ability to link contextual information to actions. In cognitive neuroscience, this aspect is known as the congruency sequence, or Gratton effect [9,12,22,44], which is a lower interference effect after a trial in which also an incompatible stimulus–response mapping (context) was evident, compared to the effect after a compatible trial. While this has been extensively researched in adults and several potential theories, concerning the congruency sequence effect have been postulated [5,12,22,44], it has never been thoroughly investigated

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concerning developmental alterations occurring between adolescence and adulthood. Yet, this is of importance, because very conclusive data shows that the medial frontal cortex and especially the ACC are important for the linking of contextual information to actions [48].

In the current study, we therefore investigate developmental changes in congruency-sequence (Gratton) effects by comparing adolescent to adult participants using a novel flanker paradigm [9] in combination with EEG and source localization analyses. For the congruency sequence effect to emerge, it has been proposed that expectancies depending on prior experience are essential [12,44]. This means that participants expect to encounter the same stimulus-response mapping in the forthcoming trial as in the current trial. So if the current trial composes a compatible stimulus-response mapping, participants will expect the same in the next trial. Such expectancy effects during response selection have recently been shown to be modulated by medial frontal areas [3,9,14,17,47,50], which are known to undergo maturational changes between adolescence and adulthood. It is therefore crucial to experimentally manipulate expectancy effects, when investigating the developmental modulation of congruency sequence effects between adolescence and adulthood. Expectancy effects can compromise performance in response selection [12,44], especially when the upcoming context is not predictable [9].

A rather counterintuitive hypothesis is that adolescents perform better than adults when the upcoming context is not predictable. Adults may always try to predict upcoming contexts (i.e., the nature of following trials), even though this is useless when the upcoming context cannot be predicted. The predictions that adults make might likely impair task performance and increase conflict. Due to the immaturity of medial frontal networks in younger age, adolescents may have problems in predicting upcoming events [10]. Even though this would usually be regarded as a deficit, it may be advantageous in unpredictable contexts. This is because under such conditions, adolescents do not have to cope with the drawbacks of useless predictions, i.e., an increase of conflict and an exacerbation of response selection. We thus predict increased reaction times in adults in unpredictable contexts, due to conflicts caused by these drawbacks, while we expect adults to perform better in predictable contexts by profiting from their predictive capabilities.

Regarding the neurophysiological level, conflict monitoring and response selection processes are reflected by the fronto-central N2 ERP [16,19,51,52]. We hypothesize that the N2 parallels the pattern found for the reaction time data; i.e., we expect to observe stronger N2 amplitude modulations when the forthcoming trial is not predictable, as compared to when the forthcoming trial is predictable. We also expect that N2 modulations between predictable and unpredictable congruency sequence effects are smaller in adolescents than in adults, because conflict is increased as an effect of useless predictions due to misleading context. At the systems level, these modulatory differences should be reflected by activation differences in the medial frontal cortex. As recent results suggest that expectancy effects during response selection are also mediated via attentional selection networks related to the parieto-occipital cortex [9], it is important to examine these processes as well. Perceptual and attentional selection processes are reflected by the P1 and N1 ERP components, respectively, which are generated in parieto-occipital regions (e.g., [24]. As these regions are also known to undergo developmental changes (review: [26] and due to the fact that attentional selection processes are refined during development (e.g., [40], differential perceptual and attentional processing of predictable and unpredictable congruency sequences in adults and adolescents might occur. However, enhanced attentional processing in adults as compared to adolescents is not necessarily beneficial for task performance. If, for example, perceptual and attentional target processing was enhanced in adults, this might lead to stronger interference effects in case of incompatible flanker-target combinations. These perceptual or attentional factors may therefore also contribute to differences in congruency sequence effects between adults and adolescents.

2. Materials and methods

2.1. Participants

Two groups of subjects were recruited for this cross-sectional study. The adult group ($n = 18$, 11 female) was aged between 20 and 30 years (mean age 26.3, SD = 3.4). The early adolescent subject group ($n = 18$, 10 female) was aged between 12.3 and 16.6 years (mean age 14.2, SD = 1.39). All subjects had no history of any neurological and psychiatric disease. Written informed consent was obtained by all participants. In case of the adolescent group, written informed consent was additionally obtained from the parents. The study was approved by the ethics committee of the TU Dresden.

2.2. Task

The task was identical to a previous publication by our group (cf. [9]): Vertically arranged arrowheads were presented. The target-stimulus was presented in the center of a screen with the arrowhead pointing to the left or right. The central stimuli were flanked by two vertically adjacent arrowheads which both pointed in the same (compatible) or opposite (incompatible) direction as the target. Participants were required to press a response button with their left or right index finger to indicate the direction the target arrow was pointing to (Fig. 1). The flankers preceded the target by 200 ms (stimulus-onset asynchrony (SOA) = 200 ms). Flankers and target(s) were switched off simultaneously. The target was displayed for 300 ms. The response-stimulus interval was 1600 ms and time pressure was administered by asking the subjects to respond within 600 ms. In trials in which reaction times (RTs) exceeded this deadline, a feedback stimulus (1000 Hz, 60 dB SPL) was presented via headphones 1200 ms after the target onset to instruct the subjects to speed up their responses.

Two different experimental blocks consisting of 120 trials (80 compatible and 40 incompatible) each were presented twice in a counterbalanced order across subjects within each group (i.e., 240 per condition and 480 in total). One block was the 'predictable block' where the trials were presented in a repetitive design to maximize expectancy effects. Trials in the predictable block were displayed in the following order: 30 compatible trials, 20 alternating compatible–incompatible trials, 20 incompatible trials, 20 alternating in compatible–compatible trials, and lastly 30 compatible trials. By means of this order, 60 (2×30) compatible–compatible (cC), 19 compatible–incompatible (cI), 19 in compatible–compatible (iC), and 21 incompatible–incompatible trial-transitions (iI) (Fig. 1) were established in each block, summing up to 120 cC, 38 cI, 38 iC and 42 iI trial transitions in the predictable condition.

In the unpredictable block, a pseudo-randomized sequence consisting of 24 trials was utilized and repeated 5 times, again summing up to a total of 120 trials. To ensure the non-occurrence of expectancy effects within the 24 trial sequence, the sequence was randomly compiled using MATLAB with a special focus on avoiding the recurrent appearance of any further unwanted short sequences within the 24 trial sequence. To do so, a sequence containing 16 compatible and 8 incompatible trials in which target arrow direction was equally distributed to the left and right was compiled in MATLAB in a pseudo-randomized order. The obtained sequence was subsequently tested in MATLAB for recurrent appearance of any further unwanted short sequences of 3 or more trials in the