CHAPTER 18

C0090 # Development of cognitive and affective control networks and decision making

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Abstract

Cognitive control and decision making are two important research areas in the realm of higher-order cognition. Control processes such as interference control and monitoring in cognitive and affective contexts have been found to influence the process of decision making. Development of control processes follows a gradual growth pattern associated with the prolonged maturation of underlying neural circuits including the lateral prefrontal cortex, anterior cingulate, and the medial prefrontal cortex. These circuits are also involved in the control of processes that influences decision making, particularly with respect to choice behavior. Developmental studies on affective control have shown distinct patterns of brain activity with adolescents showing greater activation of amygdala whereas adults showing greater activity in Au5 ventral prefrontal cortex. Conflict detection, monitoring, and adaptation involve anticipation and subsequent performance adjustments which are also critical to complex decision making. We discuss the gradual developmental patterns observed in two of our studies on conflict monitoring and adaptation in affective and nonaffective contexts. Findings of these studies indicate the need to look at the differences in the effects of the development of cognitive and affective control on decision making in children and particularly adolescents. Neuroimaging studies Au6 have shown the involvement of separable neural networks for cognitive (medial prefrontal cortex and anterior cingulate) and affective control (amygdala, ventral medial prefrontal cortex) shows that one system can affect the other also at the neural level. Hence, an understanding of the interaction and balance between the cognitive and affective brain networks may be crucial for self-regulation and decision making during the developmental period, particularly late childhood and adolescence. The chapter highlights the need for empirical investigation on the interaction between the different aspects of cognitive control and decision making from a developmental perspective.

Progress in Brain Research, Volume 202, ISSN 0079-6123, http://dx.doi.org/10.1016/B978-0-444-62604-2.00018-6

Keywords

development, cognitive control, affective control, conflict monitoring, conflict adaptation, attention network task, emotion, decision making

s0005 ## 1 INTRODUCTION

p0005 Control of thought and action is the hallmark of effective human behavior. Cognitive control is intimately related to our abilities to learn, search, and make decisions. Humans often need to choose among actions with uncertain consequences and to modify those choices according to ongoing sensory information and changing task demands (Shenoy and Yu, 2011). The requisite ability to dynamically modify or cancel planned actions is a fundamental component of cognitive control (Nigg, 2000).

p0010 One of the important features of a cognitive system is that it can configure itself for task performance through adjustments in perceptual selection, response bias, and maintenance of contextual information which is referred to as cognitive control. Conflict has been considered as the basis for the regulation of control. Conflict monitoring serves to translate the occurrence of conflict into compensatory adjustments in control referred to as conflict adaptation. Given the relationship between conflict and demand for cognitive control in resolving and monitoring the conflict, behavioral decision making should display a bias away from tasks that have given rise to conflict in the past (Botvinick, 2007).

p0015 Decision making requires monitoring and integrating conflicting information. Response conflict can occur when an incorrect response should be overridden by a correct response and also when one has to make an undetermined choice between equally compelling responses that activate different compatible pathways. In this chapter, we first present an overview of the relationship between cognitive control and decision making and the brain regions involved in control processes and decision making. The chapter would focus on control-mediated conflict monitoring and subsequent performance adjustments as one of the key processes that influence decision making. Control processes such as interference control and monitoring in cognitive and affective contexts influence the process of decision making. This relationship is particularly relevant in the case of risky behavior observed among adolescents. The reasons of such risky behavior among adolescents could be associated with the ongoing gradual maturation of control processes which may play a crucial role in shaping up the processes underlying decision making. This chapter is an attempt to bring out the need for research on the relationship between cognitive control and decision making from a developmental perspective since childhood in order to understand the decision-making mechanisms at work during adolescence. We believe that it is not only the developmental period of adolescence rather the very nature of growth patterns of control processes which may also influence the decision-making abilities at that stage.

s0010 2 COGNITIVE CONTROL AND DECISION MAKING

p0020 Cognitive control broadly refers to the ability to shape behavior in an adaptive manner in the context of the goals, constraints, and competing demands. Different aspects of cognitive control have been explained in various conceptual models (Badre, 2008; Botvinick et al., 2001; Koechlin et al., 2003). At the same time, there has been extensive research on the ability we have to make decisions adaptively. We are often faced with complex decisions requiring integration of information, dealing with uncertainty, resolving conflict across competing responses, and using strategies. The ability to deal with decision contexts such as this involves cognitive resources. There is lot of overlap between strategic control in decision making and cognitive control but very little has been done to understand the integration of the two domains of research.

p0025 Decision making involves a complex interplay of high-level process, including option generation, evaluation of risks and consequences, and choice of a course of action (Baron, 2008). Thus, decision making may require a high degree of cognitive control (Tranel et al., 1994). Consistent with this idea, a close link between frontal/executive functions and decision-making processes has been suggested by patient studies (Manes et al., 2002), brain-imaging research (De Martino, et al., 2006), and behavioral experiments (Hinson et al., 2003). Decision procedures that are sensitive to long-term consequences of options entail working memory resources and control processes. Del Missier et al. (2010) reported that there is specificity in the control requirements of different decision-making tasks. For instance, shifting is mainly involved in the capacity to provide consistent judgments on risky events, while inhibition appears to play a significant role in the accurate implementation of decision rules. They also found that consistency in risk perception depends on the ability to shift between judgment contexts.

p0030 The correlation between cognitive abilities and decision making (Stanovich and West, 2000) is based on the assumption that this link results from the fact that more able individuals have more cognitive resources enabling the computation of more normative decisions via logical processes (Evans, 2008). Brooks et al. (2010) in their neuroimaging study on decision making over negative outcomes reported enhanced BOLD response related to worse outcomes could be due to the involvement of attention or cognitive control in general. Higher activations observed in dorsomedial prefrontal cortex (dmPFC) in addition to orbitofrontal cortex and anterior cingulate for risky gambles have been implicated in decision-related control processes, being more active for more difficult decisions which involve inhibitory control, conflict monitoring, and anticipation. Various paradigms such as Eriksen's flanker task (Eriksen, 1994), Stroop task (Stroop, 1935), go-no-go task, and Simon task have been Au8, Au9 used to measure decision processes related to inhibition, conflict monitoring, and subsequent adjustments in performance. Contextual effects in decision making (Chapter 13) are also governed by control processes; for example, recent evidences on effects of emotional context on decision making with respect to choice behavior under uncertainty have shown different effects of pleasant versus unpleasant emotional contexts (Chapter 3). In the sections below, we discuss the relevance of control-mediated conflict monitoring and adaptation in decision making and then discuss two developmental studies on contextual effects on decision processes involved in conflict resolution in the context of the dissociable cognitive and affective control networks.

s0015
3 CONFLICT MONITORING, CONFLICT ADAPTATION, AND DECISION MAKING

p0035 In the context of complex decision making under uncertainty and competing demands, one needs to efficiently select, inhibit across competing stimuli, and monitor conflict. The benefits of treating performance monitoring as a decision process may be related to the fact that there are shared neural mechanisms for accumulating and evaluating evidence about external (sensory) events and internal (monitoring) processes; understanding of performance monitoring will be deepened by further investigation of these shared processes (Steinhauser and Yeung, 2010).

p0040 Conflict monitoring for emotional versus nonemotional information may be governed by different mechanisms. High conflict in an incongruent trial leads to a transient upregulation of attention in anticipation of the next trial resulting in improved conflict resolution known as conflict adaptation. The detected conflict signal then triggers strategic adjustments in cognitive control, which then serve to prevent conflict in subsequent performance. Pochon et al. (2008) examined whether the role of conflict monitoring extended to complex decisions that involve the integration of higher-order beliefs and preferences and found modulation of behavioral and neural responses as a function of high versus low decision conflict. In addition, strategic control in decision making also varies across emotional and social contexts. Conflict monitoring in an affective context could involve different cognitive and neural mechanisms. With advances in neuroimaging tools and the recent integration of cognitive and affective neuroscience, the neurobiological basis of cognitive and emotional conflict resolution has been better understood (Egner and Hirsch, 2005; Hare and Casey, 2005).

s0020
4 DISSOCIATION BETWEEN COGNITIVE AND AFFECTIVE CONTROL NETWORKS

p0045 Contextual effects in decision process include the effects of motivational, social, and affective contexts. Emotional context can differentially impact the recruitment of cognitive control. For example, positive emotional valence is related to approach and reward, whereas negative valence is associated with avoidance and withdrawal. However, the control processes that mediate affective processing have been found to be governed by a separable neural circuit. Prefrontal connectivity has been associated

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B978-0-444-62604-2.00018-6, 00018

with the efficiency of cognitive control (Nagy et al., 2004). In addition, recent research Au10 has reported a central role of dmPFC in aspects of cognitive control, particularly detection and monitoring of conflict and decision making (Venkatraman et al., 2009). Anterior cingulate cortex has been posited to signal the need for greater cognitive control that has been reported for affective control also though involving different regions of the ACC (Egner et al., 2008). Rostral ACC is known to regulate affective control, whereas dorsal ACC is reported to be associated with conflict adaptation similarly for both emotional and nonemotional information (Etkin et al., 2006). There is also evidence on the role of anterior cingulate in conflict monitoring and decision making with a proposition to reconcile the two processes (Botvinick, 2007).

p0050 In order to examine the stages of processing and precise temporal loci of experimental phenomena (Susan et al., 2007), there is some literature on the event-related Au11 potential (ERP) studies on conflict monitoring. N2 component and N450 component Au12 have been observed after the presentation of conflict stimuli (Forster et al., 2011). The N2 component lies over the frontal midline sites and is believed to have signal generation within the ACC. The N2 component increases its negativity with the higher levels of conflict, and N2 amplitudes are reduced as an effect of conflict adaptation. In our future studies, we are looking at the latency of N2 component if it would vary across emotional valences which would have implications in the context of affective influences of decision making. Modulation of N170 component has been reported in a study using face-word Stroop task indicating the modulation of decision process at the perceptual level itself in affective contexts. In a study using a gambling paradigm, authors could disentangle the modulations related to the amount of conflict involved in decision making showing an increase in central and frontal N2 and P3 components (Mennes et al., 2008). As neuroimaging studies have shown dissociation between control processes operating in affective versus nonaffective contexts, conflict monitoring might follow different developmental patterns and influence the decision process in such contexts.

s0025 5 ROLE OF COGNITIVE AND AFFECTIVE CONTROL NETWORKS IN DECISION MAKING

p0055 Many neuroimaging studies have investigated cognitive control functions in adults, such as inhibition, manipulating complex information in memory, reward processing, guessing, and planning. These functions can be broadly captured under inhibitory control and affective decision making. These studies highlight the importance of the prefrontal cortex in higher cognitive processing and also point out that this region may be fractionated further resulting in distinct neural circuits. The lateral prefrontal cortex is relevant in motoric response inhibition, manipulating information online, considering options, and updating performance outcomes (Fletcher et al., 1997). The ventromedial prefrontal cortex may be involved in best-guess estimations and emotional experience associated with gains and losses (Breitner et al., 2001). Both the lateral and ventromedial prefrontal cortex is thought to have

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close connection with the anterior cingulate cortex, which is involved in conflict processing and outcome processing (Botvinick et al., 1999).

p0060 Recent evidences have implicated the role of dmPFC in the flexible control of behavior (Brown and Braver, 2005; Carter et al., 1998). The dmPFC has been found to be associated with detection of conflict and conflict monitoring (Botvinick et al., 1999), selection among mutually incompatible responses as well as reward processing, and decision making under risk and uncertainty (Hadland et al., 2003; Rogers et al., 2004). Most of these evidences come from paradigms involving executive function or response selection such as Stroop task, Simon task, flanker task, etc., and not complex decision-making. There is also evidence to show that the dmPFC contributes to strategic control in complex decision making. Venkatraman and Huettel (2012) demonstrate that the more posterior regions of dmPFC were associated with response-related control and the middle regions with decision-related control. Activation in the anterior dmPFC signals how a decision problem is represented. Thus, there are generalized contributions of the dmPFC to cognitive control as well as specific computational roles for its subregions depending upon the task demands and context. For example, affective context may also involve the ventral anterior cingulate and amygdala in the face of conflict resolution which are not activated in the case of nonaffective contexts. Developmentally, children and adolescents show different developmental trajectories for affective and nonaffective conflict monitoring and ability to respond adaptively which may influence their ability for making complex decisions. Au13

s0030 6 DEVELOPMENT OF COGNITIVE AND AFFECTIVE CONTROL NETWORKS

p0065 Recent advances within the field of neuroimaging have given insight into the brain regions that contribute to developmental changes in cognitive control and decision making (van den Wildenberg and Crone, 2006). Children's ability to control their thoughts and actions increases as they grow older. Prefrontal cortex is a key brain region contributing to developmental changes in cognitive control and decision making.

p0070 Developmental changes in neural circuits involving the prefrontal cortex contribute to the development of control processes and decision making. Control processes such as response inhibition, task switching, and monitoring develop rapidly during childhood and continue to mature until adolescence (for review, see Kar and Srinivasan, in press). Data on developmental trajectories of attention and control processes in Indian population (5–15 years of age) using the growth curve modeling approach have shown protracted development of these processes during childhood until adolescence (Kar et al., 2011). Au14

p0075 Immature cognition is known to be susceptible to interference from competing information and actions. Including development as a factor can be a useful method to dissociate control processes involved in conflict resolution. In addition, development of conflict adaptation for affective information would inform about the mechanisms of slower maturation of regulatory behavior in children which may influence

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decision making. Conflict adaptation effects for nonaffective stimuli have been found to show a developmental change until 15 years of age with a greater impact on conflict monitoring as compared to adaptation (Baijal et al., 2011) indicating a prolonged maturation. ERP studies have also reported modulations of the amplitudes of the N2 component only after 6 years of age indicating an immature prefrontal cortex in young children. N2 amplitudes have been found to be correlated with temperamental variations among children (Buss et al., 2010) and have implications for affective risk observed among adolescents. Functional MRI studies have shown a Au15 more diffused activation in the prefrontal cortex initially, but with age, the activation becomes more localized as only relevant connections are strengthened and others are attenuated with maturity (Hare and Casey, 2005). Children show greater activity in the amygdala, while adults show greater activity in ventral prefrontal cortex during an emotional conflict (Monk et al., 2003). These findings with respect to the developmental patterns of the circuitry for control have implications for the effect of the underlying control processes on decision making among children and adolescents.

p0080 In the section below, we discuss two of our studies on decision processes involved in conflict resolution in affective and nonaffective contexts to empirically demonstrate that these processes improve gradually with age until adolescence and into young adulthood. In addition, we also hypothesized that positive versus negative emotional valence would show different effects as a function of age with younger children showing greater constriction of attention and slower conflict resolution for negative affect. The first study examined the development of conflict monitoring in children aged 6–8 and 10–13 years as compared to adults using the attention network task (ANT) with neutral stimuli as well as emotional (positive, negative, and neutral facial expressions) stimuli. In the second study, we have examined conflict monitoring as well as performance adjustments subsequent to high- versus low-conflict conditions looking at the decision process in affective contexts using the Stroop task. Through these two preliminary studies, we demonstrate the developmental trends for decision process involved in conflict resolution and adaptation in affective and nonaffective contexts.

p0085 The purpose of our studies discussed here is to indicate protracted and differential development of control-mediated decision processes as a function of affective and nonaffective contexts. Paradigms such as the flanker task or the Stroop task employed in the studies discussed below involve decision processes in the face of a neutral of affective context and responding to the target by inhibiting the irrelevant interfering distracters. Such decision processes are mediated by control processes of selection and inhibition resulting in slower or faster decision times depending on the high- versus low-conflict conditions.

s0035 7 STUDY 1

p0090 This study demonstrates decision processes associated with high- versus low-conflict conditions, preparation for the upcoming conflict, and conflict monitoring in affective (happy and sad affect) and nonaffective contexts among children (middle and

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late childhood). Conflict monitoring has been studied with paradigms such as flanker task and Stroop task. ANT (Fan et al., 2002) has also been extensively used to investigate behavioral and neural correlates of conflict resolution in addition to the alerting and orienting networks of attention. It provides the means to measure preparation as it employs different cue conditions, conflict monitoring as it involves a flanker task with compatible flankers resulting in low conflict, and incompatible flankers resulting in high amount of conflict. The decision process involved in detecting the identity of the target by inhibiting the interfering distracters (flankers) results in faster or slower reaction times for compatible versus incompatible flankers. Neuroimaging studies with ANT have suggested separable brain regions underlying the independent networks of processes such as alerting, that mediates preparing and maintaining a state of readiness; orienting, that selects sensory information by shifting and increasing attentional focus; and executive control, that is related to conflict resolution. The ANT has been tested for its reliability in developmental studies as well as the brain-based mechanisms of conflict resolution involving the lateral prefrontal cortex and the anterior cingulate (Fan et al., 2002; Rueda and Combita, in press; Rueda et al., 2004). In addition, it also informs about the attention networks that have a critical role in cognitive control processes of selection, anticipation, and inhibition, which are also implicated in control related to decision making.

p0095 There have been no studies so far on development of conflict resolution using the ANT with emotional stimuli as this could inform about the effect of affective context on perceptual decision process involved in conflict resolution. We hypothesized that there will be a decrease in flanker effect (difference between congruent and incongruent reaction time) with age as an index conflict resolution. With respect to the ANT with emotional stimuli, we expected differences between happy and sad affect with greater flanker effect for happy as compared to sad in adults as it has been reported by several studies (Fenske and Eastwood, 2003). However, we did not expect this effect to be the same for younger children though it would be the same as adults among older children. A general decrease in reaction time for happy versus sad was expected as a function of age, and an overall slowing in RTs was expected among children for both emotional stimuli. We did not form a hypothesis regarding the differences in alerting and orienting scores for happy versus sad target affect. In the following section, we discuss the two experiments with the first based on the performance on the ANT and the second with ANT using emotional stimuli.

s0040 8 EXPERIMENT 1: ANT AS A MEASURE OF PERCEPTUAL DECISION PROCESS INVOLVED IN CONFLICT RESOLUTION

s0045 8.1 Objective and method

p0100 In this experiment, we examined the age-related differences in performance on the ANT as a measure of perceptual decision process involved in conflict resolution among three age groups (6–8, 10–13 years, and adults). We employed the child version of ANT with fish pointing leftward or rightward as stimuli for children and the adult version with arrows for adults. Task was the same for all the three age groups, that is, to detect if the central target (fish/arrow) was facing toward left or right. Both the versions of ANT consisted of a fixation point followed by a cue predictive of the spatial location about the upcoming target. There were four cue conditions (no cue, center cue, spatial cue, and double cue), which provide the attentional manipulations to derive information about the alerting and orienting networks. The cue was followed by the central target fish/arrow flanked by two flankers each on either side appearing either above or below the fixation point. The participants were required to detect the direction in which the target was facing and press the corresponding key. Flankers could be congruent or incongruent to the central target which resulted in faster versus slower reaction times, respectively.

s0050
8.2 Results

p0105 The ANT-based reaction time measurements were analyzed using age × flanker type × cue conditions design as well as with age (3) × network scores (3). The age × flanker type ANOVA showed significant main effect of age, $F(2, 34) = 6.38$, $p < 0.01$, and flanker type, $F(1, 34) = 17.28$, $p < 0.001$, as well as a significant interaction between age and flanker type, $F(2, 34) = 8.47$, $p < 0.01$, indicating faster RTs for congruent as compared to incongruent flankers in each age group and a reduction in flanker effect (difference between incongruent and congruent) with increasing age (see Fig. 1). The age × flanker type × cue conditions did not show a significant three-way interaction. However, there was a significant interaction between age and network scores $F(4, 68) = 3.26$, $p < 0.05$, showing that efficiency of attention networks changed with age. The trends observed in this study need to be tested in a larger sample of children across each age level.

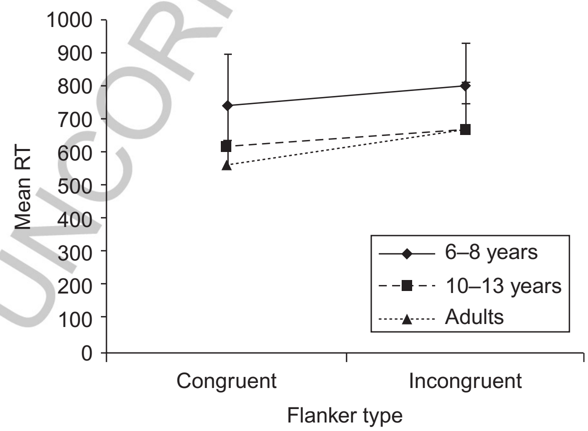

FIGURE 1

f0005 Mean reaction times for congruent and incongruent flanker types for each age group.

p0110 Results of this experiment showed improvement in conflict monitoring with age with reducing decision times on both low- and high-conflict conditions as well as the cost of conflict monitoring. With this baseline, we conducted the second experiment using the same paradigm but with affective context resulting in emotional conflict resolution.

s0055 9 EXPERIMENT 2: ANT WITH EMOTIONAL FACIAL EXPRESSIONS

s0060 9.1 Objective and method

p0115 We examined the performance on ANT as a measure of perceptual decision process involved in conflict resolution in the context of emotional stimuli for the three age groups. The effect of identity of emotion (happy vs. sad) on conflict monitoring with compatible and incompatible flankers (faces with emotional expressions) on decision times was studied in children as compared to adults. In order to detect a happy facial expression, the participant was required to inhibit the compatible or incompatible distracters which would result in greater demands on perceptual decision making in the face of flankers that were incompatible to the target affect.

p0120 Stimuli consisted of emotional facial expressions with happy sad and neutral faces with one target and two flankers on either side of the target. These stimuli were used to design the ANT with the same cue conditions and a similar time sequence as in the ANT proposed by Fan et al. (2002). The experiment had two within factors: "Cue Type" (no cue, center cue, double cue, spatial cue) and "Flanker type" (neutral, congruent, incongruent). Each target was preceded by one of four warning cue conditions: a center cue, a double cue, a spatial cue, or no cue. In the center cue condition, an asterisk is presented at the location of the fixation cross. In the double cue condition, an asterisk appears at the locations of the target above and below the fixation cross. Spatial cues involve a single asterisk presented in the position of the upcoming target. The participants were required to detect the facial expression and respond by pressing the corresponding key on the keyboard for "happy"/"sad"/ neutral expression. Reaction time was the measure of performance comparing the RTs for congruent and incongruent conditions for each target emotion across the four cue conditions. Attention network scores were also calculated for each target emotion. Figure 2 presents the trial structure of this experiment. Au16

s0065 9.2 Results

p0125 Data were analyzed to compare the performance of children and adults with respect to conflict monitoring across positive and negative affect. Figures 3–5 present the flanker compatibility effects for happy, sad, and neutral facial expressions for 6–8-year-old and 10–13-year-old children and adults (18–25 years).

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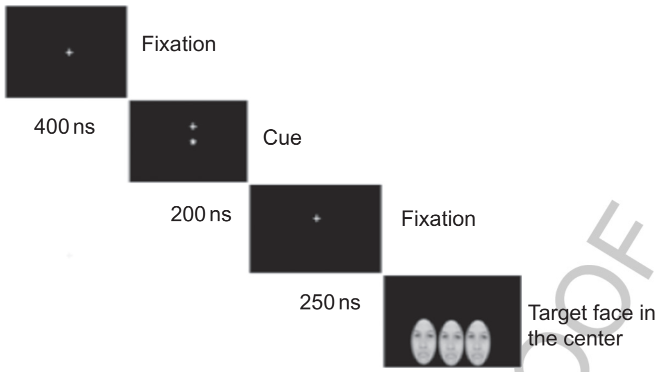

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FIGURE 2

f0010 Trial structure for the flanker task with emotional stimuli.

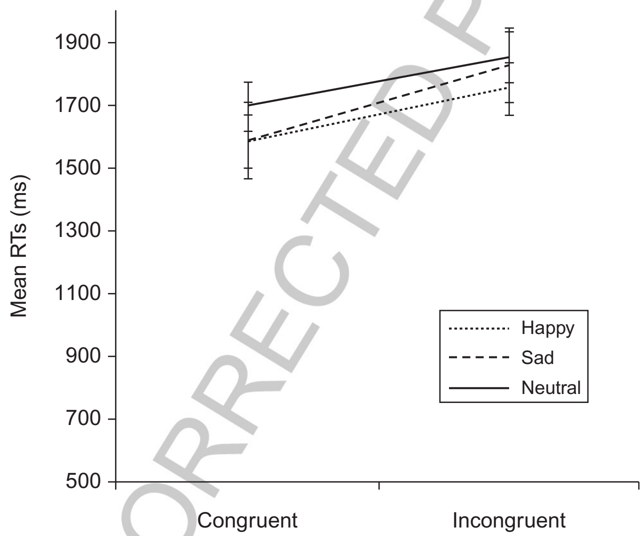

FIGURE 3

f0015 Flanker compatibility effect for positive and negative affect in 6–8-year-old children.

p0130 Four-way [3(age) × 2(emotion) × 2 (flanker type) × 4 (cue type)] ANOVA was computed with one between-subject factor (age) and three within-subject factors (emotion, flanker type, and cue type). The main effects for age, emotion, flanker type, and cue type were significant, $F(2, 34) = 30.48$, $p < 0.001$; $F(1, 34) = 15.28$, $p < 0.001$; $F(1, 34) = 46.12$, $p < 0.001$; $F(3, 102) = 9.52$, $p < 0.001$, respectively. The four-way interaction was significant, $F(6, 102) = 2.45$, $p < 0.05$. The three-way interaction of age × emotion × flanker type was also significant $F(2, 34) = 3.71$, $p < 0.05$. The two-way interactions of age × cue type, $F(6, 102) = 3.96$, $p < 0.01$, and age × flanker type, $F(2, 34) = 8.65$, $p < 0.01$, were also significant,

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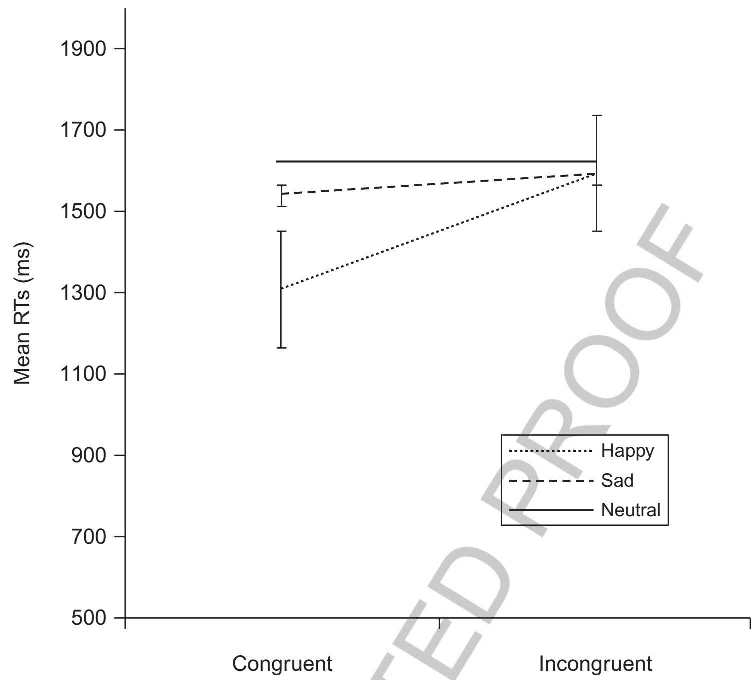

FIGURE 4

f0020 Flanker compatibility effect for positive and negative affect in 10–13-year-old children.

indicating differences in conflict monitoring and attentional control as a function of age. The magnitude of flanker effect (difference between incongruent and congruent trials) was found to decrease with increasing age, indicating an improvement in perceptual decision process even with an affective context. Greater decrease in compatibility effect was observed for positive affect as compared to negative affect. *Post hoc* comparisons indicate that younger children were generally slower than older children and older children than adults. Attention network scores (alerting, orienting, and executive control) scores did not show a significant interaction with age as well as emotion; however, the main effects for network scores and emotion were significant. Within-group comparisons were also computed. Six- to eight-year-old children did not show a significant interaction among emotion, flanker type, and cue type, or a two-way interaction between emotion and flanker compatibility. However, these interaction effects were found significant for the 10–13-year age group with greater flanker effect for happy emotion as compared to sad indicating the involved of focused attentional strategy for sad and distributed attentional strategy for happy affect (Srinivasan and Gupta, 2010).

s0070 9.3 Discussion

p0135 Results of the study suggest that there are differences in the conflict-monitoring patterns for positive and negative affect among younger and older children as well as among children and adults. These findings suggest a gradual improvement in

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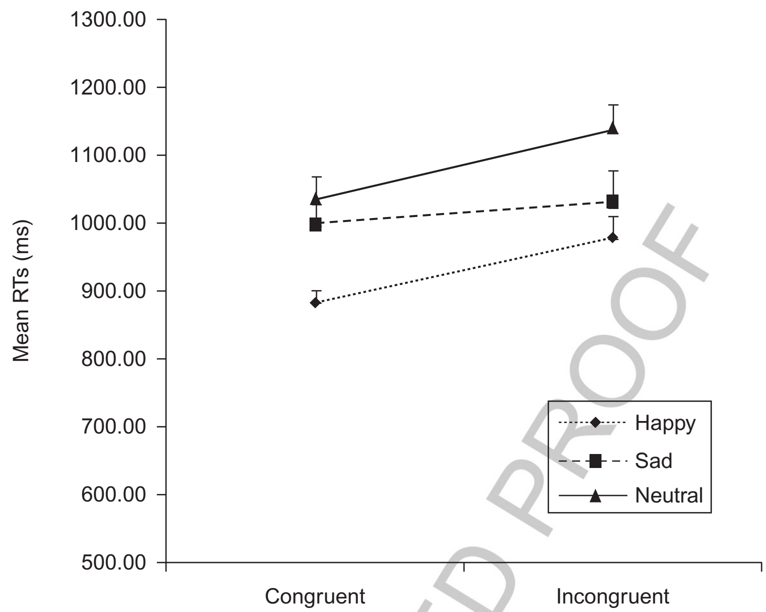

FIGURE 5

f0025 Flanker compatibility effect (conflict resolution score) for positive and negative affect among adults.

perceptual decision processes involved in conflict resolution mediated by selection and inhibition. Such studies also have implications for differences in control-mediated appraisal of reward or punishment among children and adolescents.

p0140 Results of study 1 demonstrated improvement in conflict monitoring among children indicated by the decreasing reaction times for conflict resolution as a function of age. It was interesting to note that the magnitude of flanker effect was much larger among adults as compared to children. This could be due to the much stronger representations for happy and sad emotional expressions among adults which may result in reactivating the control processes to aid in conflict resolution process and thus result in much slower reaction times for incongruent targets as compared to the congruent targets. Younger children were found to be slower on both congruent and incongruent trials, thus showing a smaller flanker effect due to general slowing. With reference to the conflict resolution performance with positive and negative affect, there was a pattern of improvement in conflict resolution for positive affect as compared to negative affect; however, younger children were much slower for negative target affect as compared to older children. Given the fact that children showed improvement in decision process involved in conflict resolution performance with age, we aimed to examine the performance-based adjustments subsequent to successful conflict resolution in our second study discussed below. The decision process that gets activated in resolving conflict in the current trial could exert its effects on subsequent trials mediated by proactive control mechanisms.

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Such effects interact with the high- versus low-conflict conditions and reduce the decision times as a function of sequential effects of congruence (Puccioni and Vallesi, 2012). Trial sequence effects as a function of congruence and demands posed by the conflict and affective context on decision processes were examined in the second study.

s0075
10 STUDY 2

p0145 The objective of the second study was to examine decision process related to conflict monitoring and subsequent performance adjustments known as conflict adaptation as modulated by the affective information in children. One of the important findings in conflict-monitoring studies is that decisions involving high interference from multiple stimulus–response representations generate longer mean response latencies than decisions with low interference (Carter et al., 1998). We hypothesized that children would also show slower response latencies for trial sequences such as congruent to an incongruent trial as compared to a congruent to congruent or incongruent to incongruent trial. This was an exploratory study as far as the conflict adaptation effects across emotional valences in children are concerned.

s0080
10.1 Method

p0150 Fifteen school-going children in the age range of 8–10 years with normal or corrected to normal vision were taken for the study. This age range was chosen, as the pilot study showed that younger children (6–8 years) as in study 1 showed $\leq 50\%$ accuracy on the face-word emotional Stroop task. Written informed consent was obtained from their parents. Experiment was based on the Stroop paradigm with faces with emotional expressions (happy or sad) taken as the target stimuli with a distractor word (happy or sad) written over the face. The word could represent an emotion either congruent or incongruent to the facial expression. The participants were required to detect the emotional expression. There were a total of 640 trials in the experiment with equal number of trials for previous and current trial pairs with respect to congruency.

s0085
10.2 Results

p0155 Mean RTs were computed for each condition for each participant. Data were subjected to a four-way repeated measures ANOVA: emotion (happy/sad) × current-trial-congruency (congruent/incongruent) × previous-trial-congruency (congruent/incongruent). The main effect of current-trial-congruency was significant $F(1, 14) = 27.351$, $p < 0.001$. There was a close to significant interaction between emotion and current-trial-congruency, $F(1, 14) = 3.812$, $p = 0.06$. Planned comparisons showed that the mean reaction time for happy congruent trials was smaller than that for the happy incongruent trials, $F(1, 14) = 3.2$, $p < 0.05$. However, the difference in

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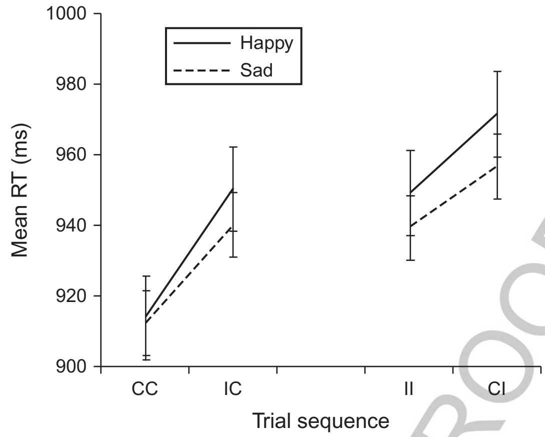

FIGURE 6

f0030 Conflict adaptation for happy and sad affect in children in the age range of 8–10 years. *Note*: CC, both current and previous trials were congruent; IC, when previous trial was incongruent and current trial was congruent; II, when both previous and current trials were incongruent; CI when previous trial was congruent and current trial was incongruent. Au1

reaction time for sad congruent and sad incongruent trials was not significant, $F(1, 14) = 1.2$, $p > 0.05$. A significant main effect of previous-trial-congruency was present, $F(1, 14) = 7.463$, $p < 0.05$. There was a significant interaction between current-trial-congruency and previous-trial-congruency, $F(1, 14) = 5.839$, $p < 0.05$, indicating the conflict adaptation effect. However, the difference in conflict adaptation effect between the two emotions was not significant (Fig. 6). Au17

s0090 10.3 Discussion

p0160 Results of the present study showed conflict monitoring and conflict adaptation for emotional information with a trend of differences emerging between the positive and the negative affect with greater conflict adaptation for positive affect and lesser conflict adaptation for negative affect among children (8–10 years). These findings indicate differences in the decision process involved in a current trial and its effects on the subsequent trial resulting in reduced congruency effects in the case of a high-conflict condition even with emotional information. These findings have implications for the evaluative functions involved in choice behavior and how a particular emotional context could affect performance monitoring. For example, our findings suggest a trend of lesser conflict adaptation for sad affect which, on a speculative level, may mean that regret as an evaluative function may have a much long-lasting effect and may be governed by the reactive control strategy. Findings of the present study indicate that children also the effect of contextual information (in this case, emotion) on decision process involved in conflict resolution. Au18

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p0165 Both the studies discussed above indicate a gradual, yet continued, development of conflict monitoring and adaptation in children with a greater use of reactive control strategy for performance adjustments. Decisions involving high interference from multiple stimulus–response representations generate longer mean response latencies than decisions with low interference in the context of affective and nonaffective stimuli. The first study employed flanker task (with preparatory cue conditions) involving decision process in the face of interference at the spatial level as opposed to the Stroop task in the second study involving decision process in the face of interference at the object level. Both flanker and Stroop task showed smaller compatibility effect for sad as compared to happy affect in children. Further studies on conflict monitoring and perceptual decision making with a developmental perspective are important since conflict monitoring and adaptation involve control-mediated mechanisms for performance adjustments in social and affective contexts which are important prerequisites for effective decision making. In the section below, we discuss the link between the cognitive and neural mechanisms of control and decision making from a developmental perspective.

s0095 11 EFFECT OF THE DEVELOPMENT OF COGNITIVE AND AFFECTIVE CONTROL ON DECISION MAKING

p0170 Cognitive and affective control governs the regulatory systems that determine one's goal-oriented behavior. Cognitive and affective control has an important impact on basic cognitive processes such as decision making and behavioral choice. The studies discussed above demonstrate that the development of decision process involved in conflict monitoring and subsequent performance adjustments matures gradually until late childhood. Hence, in addition to the slow maturation of different regions of the prefrontal cortex and anterior cingulate, the control mechanisms underlying the decision process may account for the decision-making behavior among children and adolescents. In addition, the decision process in affective context may also follow its own developmental trajectory as observed in our study which may influence the mechanisms that govern one's understanding of contextual information and may in turn affect decision making in children and adolescents.

p0175 Behavioral data have often depicted that children and adolescents are poor decision makers attributing it to their ongoing maturation of cognitive abilities such as inhibitory control that are relevant to decision making. In contrast, there is evidence showing that children and adolescents, in particular, engage in risky behavior, knowing and understanding the risk and its consequences, thus demonstrating substantial control over their thought and actions (Steinberg, 2005). Development of integrated and controlled regulatory capacities is a long process. During childhood and adolescence, the development of fully controlled regulatory systems is associated with a wide range of choice behaviors and decision making. Researchers in the field of developmental cognitive neuroscience have shown a significant growth in prefrontal cortex with respect to myelination and synaptic pruning (Sowell et al., 2002). These

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changes may result in improvements in executive functioning, control, and self-regulation. In addition, studies have also shown parallel improvement in the functioning of the ventromedial prefrontal cortex related to calibration of risk and reward (Crone and van der Molen, 2004). Cognitive and affective control development in children has been found to be gradual as evident in the studies discussed above. These processes are implicated in control related to decision making and are also mediated by the same circuits that are also involved in decision making.

p0180 The cognitive control system which involves controlling impulses, planning ahead, and other executive functions continues to develop through childhood until adolescence. Separable developmental trajectories have been reported for the neural regions such as anterior cingulate, dorsolateral prefrontal cortex, parietal cortex, and orbitofrontal cortex underlying performance adjustment and feedback utilization and monitoring, important for decision making. ACC and DLPFC keep developing even after the age of 14–15 years (Crone et al., 2008). Other than the changes in cognitive control functions in late childhood, adolescence is also the time when changes in affect and self-regulation occur and may modulate the development of control systems. Huizenga et al. (2007) conducted the IOWA gambling task with adolescents and showed age-related shift in self-regulation. Young children chose immediate high rewards and adults followed a long-term strategy. Such changes in choice behavior were observed until adolescence. Changes in control systems are present under the context of affective conditions (reward, punishment). Not only does affective informa- Au19 tion modulate cognitive control functions, but also development of cognitive control may facilitate affective processing, particularly emotional conflict resolution. Wang et al. (2007) reported an imbalance between the attention and affective networks, particularly in adolescence. However, the dissociable neural networks of cognitive control including anterior medial prefrontal cortex and anterior cingulate and that of affective control including amygdala and ventral medial prefrontal cortex inform that one system can affect the other at the neural level also (Crone, 2009). Therefore, modulations in control processes during various developmental stages could be the result of the imbalance and subsequent compensatory mechanisms in the cognitive and affective brain networks. Developmentally, it is possible that protracted development of control systems may interact with the imbalance between cognitive and affective control.

p0185 During childhood and adolescence, children gain greater cognitive flexibility and inhibitory control. Hence, there could be both independent and interactive effects of the cognitive and affective control networks on decision making. Since these systems have a prolonged course of development as well as varying patterns of influence of one set of brain regions on another and vice versa, one needs to investigate such modulations in control across developmental stages as compared to adulthood. The functional differences in reward processing occur in parallel with ongoing structural and functional maturation. Children and adolescents may be limited in their abilities to inhibit impulsive behaviors and reliably hold "online" comparisons of potential rewards/punishments during decision making (Geire and Luna, 2009). Direct impact of the immature control systems on decision making as a function of age in children until adolescence needs to be tested empirically.

p0190 May et al. (2004) reported that adolescents and adults recruit similar brain regions in a guessing game, including ventrolateral and medial prefrontal cortex. Au20 A strong correlation between age and anticipatory neural activity in ventral striatum, Au21 insula, dorsal thalamus, and dorsal midbrain while preparing for a risky decision. The developmental changes in decision making may be associated with reduced anticipatory warning signals before making a high-risk decision, as evidenced by reduced autonomic activity (Crone and van der Molen, 2007) and reduced neural activity in reward-associated brain regions (Bjork et al., 2004).

p0195 van den Wildenberg and Crone (2006) investigated two aspects of cognitive control development: inhibitory control, primarily mediated by the lateral prefrontal cortex, and affective decision making, primarily mediated by the ventromedial prefrontal cortex. In addition, developmental studies on the relationship between cognitive control and decision making have mostly aimed at understanding risky behavior of adolescents. One theory suggests risk taking in adolescence results from a mismatch in the maturity of emotional control systems and cognitive control systems (Steinberg, 2005). Given the complex temporal development pattern of emotional and cognitive control functions, it has been difficult to link such development patterns to actual decision making among adolescents. Cross-sectional and longitudinal MRI studies have shown changes in gray-matter density from childhood to early adulthood which also supports the preposition mentioned above (Toga et al., 2006). The prefrontal regions may not be fully "mature" until the mid-1920s. Future studies need to resolve the respective roles of biology, development of cognitive control, and life experience in decision making among adolescents and young adults.

p0200 In addition to the work on understanding the link between cognitive control and decision-making patterns among adolescents, the examination of developmental changes in cognitive control functions and their influence on decision making from the perspective of cognitive neuroscience could also aid in better characterizations of behavioral deficits observed in children. In one of the studies on children with attention-deficit hyperactivity disorder, it was found that control processes such as task switching, error monitoring, and response inhibition did not show any improvement with age in 6–9-year-old children with ADHD and this was correlated with performance on a choice-delay task where children with ADHD preferred to choose short-delay small reward as compared to long-delay large reward (Gupta and Kar, 2009; Gupta et al., 2011). Future research could enhance our understanding about the development and functional role of cognitive and affective control and decision-making systems to identify the neural substrates involved in the pathophysiology of impulse disorders and also to understand risky decision making among children and adolescents.

s0100

12 CONCLUDING REMARKS AND DIRECTIONS FOR FUTURE RESEARCH

p0205 Cognitive control mediates strategic control in decision making, and processes such as selection, monitoring, and inhibitory control underlie effective decision making in the face of competing demands. Botvinick (2007) has proposed reconciliation between conflict-monitoring and decision-making accounts suggesting an extension of the conflict-monitoring theory by which conflict would act as a teaching signal driving a form of avoidance learning and as a mechanism it would behavioral decision making toward cognitively efficient tasks and strategies. There seems to be a reasonable dissociation in the neurocognitive mechanisms that mediate cognitive and affective conflict monitoring. Other than the role of anterior cingulate in conflict monitoring, two separable systems have been proposed: dorsal cingulate and dmPFC connected to lateral prefrontal and motor cortices for cognitive control and conflict monitoring, whereas ventral cingulate and rostral component activations modulated by amygdala for affective control. These networks are expected to have a protracted developmental pattern at the level of both neural and cognitive mechanisms. The development of control processes interacts with decision-making process and choice behavior. Hence, future research could investigate the effect of such a prolonged development of control processes on social-emotional decision making preferably with longitudinal studies from middle childhood until adolescence. Such an inquiry would also inform about the formation of extensive networks involved in decision making. Au22

Acknowledgments

p0210 We acknowledge the Department of Science and Technology, Government of India, for the grant support (SR/CSI/29/2010) for our project on neurocognitive mechanisms of conflict adaptation for affective control funded under the Cognitive Science Research Initiative of the DST.

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