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Emotional Modulation of the Ability to Inhibit a Prepotent Response During Childhood

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ABSTRACT

The present study examined the bottom-up influence of emotional context on response inhibition, an issue that remains largely unstudied in children. Thus, 62 participants, aged from 6 to 13 years old, were assessed with three stop signal tasks: one with circles, one with neutral faces, and one with emotional faces (happy and sad). Results showed that emotional context altered response inhibition ability in childhood. However, no interaction between age and emotional influence on response inhibition was found. Positive emotions were recognized faster than negative emotions, but the valence did not have a significant influence on response inhibition abilities.

Within a developmental perspective, emotion and cognition, two subsystems that work together to process information or execute action "in the moment" (Cacioppo & Berntson, 1999) may be seen as progressively integrated during development (Lewis & Douglas, 1998). For this reason, the integration of these subsystems is a major concern when seeking to conceptualize children's development (e.g., Rothbart, 2004). More precisely, cognitive processes may allow the regulation of a child's emotional behavior and likewise, emotions could allow the organization of behavior, by modifying the child's thinking, learning, and action (Cole, Martin, & Dennis, 2004). Thus, it has been suggested that an optimal balance between emotion and cognition supports the organization of developmental processes (Blair & Dennis, 2010). In particular, Bell and Wolfe (2004) proposed that emotion and cognition are dynamically linked to allow the development of self-regulation. According to Rothbart (2004), self-regulation refers to processes that modulate emotional reactivity (i.e., individual differences in emotional response induced by emotional stimuli). Thus, self-regulation represents effortful control processes (e.g., capacity to withhold a dominant response in favor of a non-dominant one), which regulate the more reactive tendencies of individuals (Rothbart & Bates, 1998). For Fernandez-Duque and Posner (2001), effortful control is linked to the anterior attentional system (or executive system) underpinned by the anterior cingulate cortex (Bell & Wolfe, 2004). This brain structure can be separated into two major subdivisions: those supporting emotional processing and those supporting cognitive

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processes (for a review see Bush, Luu, & Posner, 2000), giving a neurobiological basis to the integration between cognition and emotion. With its intermediary role, the anterior cingulate cortex integrates the emotional reactive and cognitive control areas of the brain (Luu & Tucker, 2004) in order to keep an optimal balance between emotion and cognition (Blair & Dennis, 2010). In other words, this structure allows the integration of a bottom-up influence of emotional arousal and of a top-down effortful cognitive control of the prefrontal cortex.

More specifically, the present study focused on the bottom-up influence of emotional context on response inhibition (an effortful cognitive control mechanism), which is a hallmark of effortful regulation of emotion (e.g., Derryberry & Rothbart, 1997; Rothbart & Bates, 1998). Response inhibition refers to the ability to suppress a prepotent or dominant response that is no longer relevant. To assess this ability, two paradigms have often been used: the Go/No-Go paradigm (Donders, 1868/1969) and the stop signal paradigm (Logan, 1994; Logan & Cowan, 1984). In the Go/No-Go paradigm, participants must respond as quickly and accurately as possible for one type of stimulus ("go" trials, representing 75% of the trials) and must not respond for another type of stimulus ("no-go" trials, representing 25% of the trials). In the stop signal paradigm, participants primarily perform a go task (generally a choice reaction time task) and occasionally (about 25% of the trials) a stop signal ("stop" trials) is presented that instructs participants to withhold their ongoing response. For a long time, both types of paradigm were considered to assess similar aspects of response inhibition (e.g., Aron, 2007). However, a recent study conducted by Verbruggen and Logan (2008) demonstrated that automatic response inhibition processes could develop in the Go/No-Go paradigm, because of the consistent association between the stimuli and the response that allows the development of automatic associative learning through practice. Thus, inhibition of response could be achieved through automatic memory retrieval. In contrast, in the stop signal paradigm, because the mapping rules between stimuli and response are inconsistent (the stop signal is presented after the go stimulus), the maintenance of executive control (i.e., effortful) processes is required in order to inhibit the response.

Age-related improvement of response inhibition abilities during childhood, as measured with the stop signal paradigm, has been reported in several studies. For example, Williams, Ponesse, Schachar, Logan, and Tannock (1999) and Bedard et al. (2002) reported an improvement in the performances of children aged 9 to 12 years compared to those aged 6 to 8 on response inhibition (measured with the stop signal reaction time, SSRT). Furthermore, in Ridderinkhof, Band, and Logan's (1999) as well as van den Wildenberg and van der Molen's (2004) studies, the inhibition of a prepotent response became more efficient (decreasing SSRT) throughout three age groups (7-year-old > 10-year-old > 22-year-old). More recently, Huizinga, Dolan, and van der Molen (2006) reported that response inhibition became more efficient up to age 15. Tillman, Thorell, Brocki, and Bohlin (2008) assessed children aged from 4 to 12 and pointed out that the SSRT decreased between 5 and 6 and between 6 and 8 years of age, indicating an improvement in the ability to inhibit a prepotent response. Finally, a study by Urben, Van der Linden, and Barisnikov (2011) showed an improvement in response inhibition during childhood as measured by the stop signal paradigm (5-6 years > 7-8 years > 9-10 years = 11-12 years), even after controlling for processing speed and working memory improvement.

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With regard to the influence of emotional context on response inhibition, during the last decade, few studies have explored this influence with child samples (e.g., Todd, Lewis, Meusel, & Zelazo, 2008) or with samples including children, adolescents and adults (e.g., Somerville, Hare, & Casey, 2011). However, this topic has been studied intensively in adult or adolescent populations through behavioral studies (e.g., Schulz et al., 2007; Verbruggen & De Houwer, 2007) or neuroimaging studies (e.g., Albert, Lopez-Martin, & Carretie, 2010). Thus, to study the interaction between emotion and response inhibition, numerous experimental designs have been developed to assess the influence of emotional context on response inhibition. Within this context, the next part of the introduction will allow a better comprehension of our methodological choices. First, we report studies exploring the emotional influence within indirect processing of emotional information and highlight the difficulties involved in such methodology. Then, we discuss studies adopting the same methodology as ours (i.e., replacing neutral material by emotional material) while studying adults or children.

For example, Verbruggen and De Houwer (2007) explored the influence of interfering emotional stimuli on the inhibition of a prepotent response in a sample of young adults. The authors introduced interfering emotional stimuli (emotional pictures from the International Affective Picture System (IAPS), Lang, Bradley, & Cuthbert, 2008) while the participant was completing a stop signal task on neutral material (symbols "#" and "@"). Results showed increasing response time latencies for "go" trials and for the SSRT when an interfering emotional picture was presented. Likewise, Lewis, Lamm, Segalowitz, Stieben, and Zelazo, (2006) developed an affective Go/No-Go task and assessed 58 children and adolescents aged 5 to 16. In their modified Go/No-Go task, go stimuli were letters whereas the inhibition of the response (no-go) was triggered by the repetition of the letters. In addition, they instructed the children and adolescents that they had to earn a maximum number of points to win a desirable prize. The authors manipulated the attribution of points experimentally in order to give a negative affective valence to the second block (loss of all points previously won) and a positive one to the third block of trials (accumulation of many points). Results showed a deleterious effect of the negative affect induction on the global performance (accuracy averaged between go and no-go trials) and negative affect had a greater influence on the performances of younger children. When studying the emotional influence using such "indirect" methodology, it is not possible to be sure of the source of influence on the performances and even if the emotional material is processed. In addition, in the study of Lewis et al. (2006), it was not certain that the loss of the points had the same impact on all children, which may depend on motivational aspects. To respond to such criticisms, other studies adopted a methodology which made it possible to control whether the emotional material was correctly processed or not.

Indeed, other studies, assessing the interaction between emotion and response inhibition, have used experimental designs where neutral stimuli in classical inhibition tasks are replaced by emotional words (Goldstein et al., 2007, for example) or pictures (Schulz et al., 2007, for example). In this context, Hare, Tottenham, Davidson, Glover, and Casey (2005), for example, presented 10 adults with a Go/No-Go task using affective faces (joyful, fearful, or neutral). Results indicated that the fearful facial expression was associated with longer reaction times in go trials and joy was related to poorer performances in inhibitory processes compared to the trials using neutral faces. In a similar way, Schulz et al. (2007) assessed 85 participants aged from 18 to 66 years old (M = 26.12, SD = 10.83) with two versions of a

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Go/No-Go task, one composed of neutral stimuli (red and green circles) and the other of emotional stimuli (faces with happy and sad expressions). Results showed a deleterious effect of emotional faces on the go (slower go reaction time) and no-go (more commission errors) performances. Moreover, regarding the emotional version of the Go/No-Go task, Schulz et al. (2007) observed a bias for positive emotion. Thus, for these trials participants had shorter reaction times and more commission errors compared to trials with negative emotion. The bias for positive emotion has been explained by the link between positive emotion and approach behavior (Johansson & Ronnberg, 1996) resulting in shorter reaction time for happy faces compared to sad faces. Finally, Schulz et al. (2007) tested the effect of participants' gender and age (above and below 20 years, which was the median in their population), but reported neither gender effect nor age effect. All the studies presented above led us to believe that response inhibition may be hampered by the presentation of emotional material. However, few studies adopted this methodology with child populations.

In this perspective, two studies have explored the impact on response inhibition of presenting emotional faces. Lewis, Todd, and Honsberger (2007) presented 18 children aged 4 to 6 with a Go/No-Go task with happy, angry, and neutral faces as stimuli. Results indicated a significant impact of the valence of the emotion on go trials, with the shortest response latencies for happy faces, medium for neutral faces, and longest for angry faces. Nevertheless, the emotional context did not have an influence on no-go trials. In addition, Todd et al. (2008) proposed a Go/No- Go task showing happy or angry faces of the child's own mother or of an unknown mother to 48 children aged from 4 to 6. Results did not show any significant influence of the type of material on either the response time latencies or on the response inhibition abilities. The lack of modulation of emotional context in these studies, which contrasts with previously reported studies on adults, was probably due to the high accuracy rates in the task (over 95%). Furthermore, the use of the Go/No-Go paradigm did not make it possible to assess controlled (i.e., effortful) response inhibition processes, at least in adult populations (Verbruggen & Logan, 2008). To the best of our knowledge, no study has explored the influence of emotional context (using faces presenting emotional expressions) on response inhibition abilities as measured with a stop signal paradigm in middle childhood, which has been shown to be an important period of development for these effortful control processes. Such studies should make it possible to better understand the influence of emotional context on the development of effortful processes.

Thus, in the current study, we administered three versions of a stop signal task, in which only the material differed, to 62 children aged from 6 to 13. The first version used circles of different colors as the main stimuli (henceforth referred to as neutral material), the second version used faces presenting neutral expressions (henceforth referred to as neutral faces) and the third version was composed of faces presenting emotional expressions (happiness and sadness; henceforth referred to as emotional faces). The three versions of the task were intended to allow us to differentiate between the impact of face processing and the influence of emotion processing on response inhibition. In light of the literature, four main hypotheses can be formulated. First, given previous studies exploring the development of response inhibition abilities, we will observe developmental trends during the period of age under study. Second, we could hypothesize that the ability to inhibit a prepotent response will suffer from an emotional context as has been demonstrated in previous studies. Third, as Lewis et al. (2006) report

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that, with increasing age, children are less impaired by emotional context in their performances in a Go/No-Go task; we hypothesize that response inhibition abilities of older children will be less hampered by the emotional material than younger children. Fourth, given the relationship between approach behavior and positive emotion, response latencies in reaction to happy faces will be shorter than latencies in reaction to negative emotion.

METHOD

PARTICIPANTS

A total of 62 children took part in the experiment. All children were recruited from the same public elementary school in Geneva. The participants performed the Coloured Progressive Matrices (Raven, Court, & Raven, 1998) and had a percentile score that corresponded to their age and that was above the fifth percentile, indicating sufficient non verbal reasoning abilities. Two children refused to complete all tasks; therefore their data were not included in further analyses. The 60 children included in the analyses (35 girls; mean age, *M* = 9.73 years; standard deviation, *SD* = 2.20 years; age range: 6.0-13.40) were divided into two groups of children. The group of younger children comprised 30 children (*M* = 7.66; *SD* = 0.63; age range: 6.0-8.85; 11 boys and 19 girls) and the group of older children also consisted of 30 children (*M* = 11.78; *SD* = 0.83; age range: 9.61-13.40; 14 boys and 16 girls). The age groups were chosen first to be comparable to previous studies exploring developmental trends in response inhibition (e.g., Bedard et al., 2002; Urben et al., 2011; Williams et al., 1999). The age groups were also chosen because the study of Tillman et al. (2008) demonstrated that the ability to inhibit a prepotent response, as measured with the SSRT, emerged around 6 years of age. Furthermore, response inhibition abilities were demonstrated to reach adult level in late childhood or early adolescence (Bedard et al., 2002; Van den Wildenberg & Van der Molen, 2004; Williams et al., 1999). In addition, it is important to note that the prefrontal cortex is an important structure for response inhibition (Aaron, 2007). Thus, this late development of response inhibition could be related to the protracted maturation of the prefrontal cortex (e.g., Diamond, 2002). Thus, the age groups of the current study covered an important period of maturation of response inhibition. The sample (ranging from age 6 to 13) was split at 9 years of age, in order to have equal groups' sizes for the statistical analyses. A Chi-square analysis comparing the proportion of males and females between the age groups showed no significant differences, ($\chi^2 = 0.62$, $p = .43$). The consent for child participants was delivered by the Cantonal Authorities for Primary Education and the school administration authorities; and children participated as volunteers. The study was approved by the Ethics Committee of the Faculty of Psychology (University of Geneva).

APPARATUS AND PROCEDURE

The tasks consisted of three versions of the stop signal paradigm, which varied only on the nature of the stimuli (neutral material (colored circles), neutral faces, and emotional faces). The presentation of facial expressions was chosen because it is a natural way to represent and induce emotion and because the method is easy to use with young children. In contrast, with emotional pictures, it would have been harder to control the complexity of the stimuli and to control their valence and level of arousal, which could vary a lot. In addition, if we had chosen emotional words, young children who were not good

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readers would have had difficulty performing the tasks.

The various versions of the tasks had the same structure, timing parameters, trial order, and response demands, differing only in the stimuli used. The stimuli (circles or faces) were of the same size. The tasks were administered in a quiet room, by a trained psychologist. Children were instructed to respond as quickly and accurately as possible and received additional instructions to avoid waiting for the occurrence of the stop signal. Children faced the computer screen at a distance of approximately 50 cm. All stop signal tasks were compiled and run using E-Prime™ software version 1.2 (Psychology Software Tools, Inc., Pittsburgh, PA; Schneider, Eschman, & Zuccolotto, 2002). The order of the administration of the tasks was counterbalanced across participants. In addition, the number of "go" and "stop" trials was the same across all tasks.

Stop signal task with neutral material. The first part of the task began with 24 trials of a choice reaction time. The participants had to press two response keys (button /c/ or /m/, mapping rules counterbalanced across participants) as a function of the color of a circle (orange or blue). The first part of the task was used to compute the mean reaction time in order to set the stop signal delay for the first test block. The two response keys were marked with different signs in order to avoid additional working memory demands. A trial began with a fixation cross during 500 to 1,000 msec (timing created randomly by the software). The presentation of each stimulus was ended by the participant's response, or 1,000 msec after the stimulus onset. Then, in the second part, the stop signal task started. It consisted of ten training trials with 3 stop signals, followed by 4 test-blocks of 48 trials, of which 12 trials (25%) included a stop signal. The stop signal consisted of a red square appearing around the circle (go stimulus) after a delay (stop signal delay, SSD) fixed by subtracting 0 to 500 msec (in increments of 100 msec) from the mean reaction time, as proposed by Logan (1994). For the first test-block of the task, the mean reaction time was calculated from the first 24 trials. For the second test-block, the mean reaction time was computed from the correct trials from the first test-block, and so on. When the subtraction gave negative results, the stop signal delay was fixed at 50 msec after the onset of the stimulus. The adaptation of the SSD (through the blocks) is a standard procedure (Schachar & Logan, 1990) allowing avoiding strategies and taking into account intra-individual differences in response variability.

Stop signal task with neutral faces. The stimuli of the neutral faces version of the task consisted of neutral facial expressions from 12 individuals (6 female and 6 male, all white people; female model number: 01; 02; 03; 06; 07; 09; male model number: 21; 24; 29; 30; 34; 36) selected from the Macbrain Face Stimulus Set available at www.macbrain.org. Participants had to decide if the face presented was a male or a female one by pressing one of two response keys (button /c/ or /m/, mapping rules counterbalanced across participants). The two response keys were also marked with different pictures (male/female) in order to avoid additional working memory demands.

Stop signal task with emotional faces. The stimuli of the emotional version of the task consisted of happy and sad facial expressions from the same 12 individuals, as in the neutral facial expression version, selected from the Macbrain Face Stimulus Set available at www.macbrain. org. The presentation of the same individual faces was chosen in order to avoid variability in the material presented. In addition, as the presentation of the tasks was counterbalanced across participants, practice effect due to the

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repetition of the presentation of the stimuli was avoided. Participants had to decide if the face presented a happy or a sad expression by pressing one of two response keys (button /c/ or /m/, mapping rules counterbalanced across participants). The two response keys were also marked with different smileys (happy/sad) in order to avoid additional working memory demands.

MEASURES

For the "go" trials (execution of the response), the *percentage of correct responses* (mean success rate) was computed. In order to compute the *median go reaction time (MRT),* responses in less than 200 msec were considered as anticipated and not in reaction to the stimulus; therefore this type of response was not taken into consideration. In addition, all reaction times over 2.5 standard deviations from the original mean reaction time, computed for each participant, were also excluded (less than 2% for all tasks). Then, we also computed the *standard deviation (SD).* The scores computed for the "stop" trials (inhibition process) were the *percentage of inhibited trials* (mean success rate) and the *stop signal reaction time (SSRT).* Following a standard procedure proposed by Logan (1994), the SSRT was estimated as follows: the reaction times for "go" trials were rank-ordered and the *n*th reaction time (excluding reaction times over 2.5 standard deviations and less than 200 msec) was found, where *n* was the percentage of failed response inhibition (probability of responding) for each delay. Then, we subtracted the SSD (averaged across the blocks) of this *n*th's reaction time. Finally, in order to estimate the global SSRT, we averaged the SSRT computed for each SSD.

RESULTS

DATA ANALYSIS

Firstly, gender differences were tested with independent sample *t*-tests. As results revealed no differences, the data of males and females were averaged and analyzed together. Then, we conducted analyses (ANOVAs and correlational analyses) in order to explore the influence of the type of material and the possible interaction with developmental trends. To ensure that age effect on SSRT is not due to faster responses in older children, we conducted partial correlational analyses between MRT and SSRT (which allow us to test the independency assumption postulated in the horserace model). Finally, in order to study the influence of the valence of the emotion on the performances, ANOVAs were computed on the main scores of the stop signal task with the emotional faces. No analyses were conducted regarding the mean success rate of stop trials, as this score was experimentally influenced by the delay before the stop signal.

First, Table 1 presents the performances in the three versions of the stop signal, for the whole sample and for each age group.

DEVELOPMENTAL TRENDS AND INFLUENCE OF THE TYPE OF MATERIAL

In order to observe developmental trends in response inhibition and to look for a possible interaction with the type of material, we conducted a 2 (age groups) x 3 (material: neutral material, neutral faces, and emotional faces) ANOVA on the SSRT. The analyses revealed a main effect of the age group, $F(1, 58)$

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= 30.99, $p < .001$, $\eta_P^2 = 0.35$ (shorter SSRT for the older children), a main effect of the type of material, $F(2, 116) = 15.37$, $p < .001$, $\eta_P^2 = 0.21$, but no interaction between these factors. Post hoc comparisons with Bonferroni correction showed a significantly higher SSRT measured with emotional expressions compared to the SSRT measured with neutral material ($p < .001$) or compared to the SSRT measured with neutral faces ($p \leq .001$). To ensure that the lack of interaction effect between emotion, response inhibition and age was not due to a lack of statistical power, we computed ratios reflecting the emotional modulation to correlate them to age. The ratios of the emotional modulation were computed as follows: [(SSRT with emotional faces - SSRT for neutral faces)/SSRT for neutral faces] and [(SSRT with emotional faces - SSRT for neutral material)/SSRT for neutral material]. The correlations between these ratios and age were not significant ($r = -.01$ $p > .10$; $r = .05$ $p > .10$, for the ratios computed with neutral faces and neutral material, respectively). This second analysis ensured the lack of age-related changes in emotional modulation in the present data.

TABLE 1 - Mean (and Standard Deviation) for Stop Signal Measures Regarding the Material, for the Whole Sample and by Age Groups

		Tasks		
Samples	*Measures*	*Neutral Material*	*Neutral Faces*	*Emotional Faces*
Whole sample	MRT	662.46 (106.09)	727.45 (111.10)	816.04 (119.05)
(*N* = 60)	*SD* of MRT	172.30 (48.61)	173.83 (43.93)	184.37 (51.59)
	ACC "go"	0.91 (0.07)	0.88 (0.09)	0.76(0.13)
	ACC "stop"	0.56(0.14)	0.55 (0.11)	0.51 (0.12)
	SSRT	277.01 (94.24)	287.31 (80.86)	334.88 (95.76)
Young children	MRT	714.40 (87.57)	786.02(96.14)	881.97 (113.82)
(*n* = 30)	*SD* of MRT	201.41 (45.54)	198.49 (42.67)	214.03 (54.26)
	ACC "go"	0.88 (0.07)	0.84 (0.10)	0.71 (0.14)
	ACC "stop"	0.52(0.13)	0.50(0.12)	0.49 (0.14)
	SSRT	321.90(100.15)	325.93 (78.55)	384.35 (90.18)
Old children	MRT	610.52 (98.22)	668.88 (93.67)	750.12(82.98)
(*n* = 30)	*SD* of MRT	143.18 (31.32)	149.16(29.11)	154.72 (25.52)
	ACC "go"	0.94 (0.05)	0.92 (0.06)	0.82(0.11)
	ACC "stop"	0.61 (0.13)	0.59 (0.09)	0.53 (0.10)
	SSRT	232.11 (62.19)	248.69 (63.61)	285.41 (73.89)

Note. MRT = median reaction time for "go" trials; SD of MRT = standard deviation of the median reaction time; ACC "go" = mean success rate for "go" trials; ACC "stop" = mean success rate for "stop" trials; SSRT = stop signal reaction time.

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Then, to verify the independency assumption between "go" and "stop" processes in the stop signal paradigm, postulated by the horse-race model, partial correlations (with age partially out) were computed between the MRT and the SSRT of each task. This analysis revealed no significant correlation ($-.10 < r < .17$, $ps > .10$), indicating that the main effect of age group on SSRT is not simply a function of faster RTs in the older group.

INFLUENCE OF THE TYPE OF EMOTION ON THE PERFORMANCE

Then, in order to observe the influence of the valence of emotion and age on performance, we conducted 2 (age group) x 2 (valence: happy and sad facial expression) ANOVAs on the MRT, on the *SD,* on the success rate in "go" trials and on the SSRT.

The analyses related to the MRT revealed a main effect of the age group, $F(1, 58) = 24.06$, $p < .001$, $\eta_P^2 = 0.29$ (shorter MRT for older children). In addition, we found that happy expressions were recognised faster than sad expressions, $F(1, 58) = 9.36$, $p < .01$, $\eta_P^2 = 0.14$, but the interaction effect did not reach significance.

In order to examine the age-related changes in the variability of the response, we conducted a 2 (age groups) x 2 (emotion's valence) ANOVA on the coefficient of variation (SD/mean RT). The analysis showed a main effect of the age group, $F(1, 58) = 8.82$, $p < .01$, $\eta_P^2 = 0.13$, a main effect of the emotion's valence, $F(1, 58) = 11.16$, $p < .001$, $\eta_P^2 = 0.16$, but the interaction effect was not significant. Thus, younger children responded with more variability than older children. Furthermore, children in general responded with more variability to happy faces than to sad faces. Concerning the analyses conducted on the mean success rate of the "go" trials, results revealed a main effect of the age group, $F(1, 58) = 12.14$, $p < .001$, $n_p^2 = 0.17$ and a main effect of the valence $F(1, 58) = 5.88$, $p < .05$, $\eta_P^2 = 0.09$ (in favor of happy facial expressions). However, the interaction effect did not reach significance.

Finally, the ANOVA conducted on the SSRT revealed a main effect of the age group, $F(1, 58) = 19.24$, $p < .001$, $\eta_P^2 = 0.25$, but neither a main effect of the valence of the emotion, nor an interaction effect.

DISCUSSION

The aim of the present study was to explore, within a developmental perspective, the impact of emotional context on a hallmark effortful executive mechanism. Results revealed three main findings. First, age-related trends were found in relation to response inhibition abilities. Second, the emotional context hampered an efficient functioning of the ability to inhibit a prepotent response. Finally, this modulation of response inhibition by emotional context seemed not to evolve during childhood.

In particular, with regard to the development of response inhibition abilities, results demonstrated developmental trends during childhood, which is consistent with the majority of studies exploring the development of response inhibition (Bedard et al., 2002; Huizinga et al., 2006; Ridderinkhof et al., 1999; Tillman et al., 2008; Urben et al., 2011; van den Wildenberg & van der Molen, 2004; Williams et al., 1999). In contrast, some studies have not found any development in response inhibition (e.g., Band, van der Molen, Overtoom, & Verbaten, 2000; Schachar & Logan, 1990). However, these studies suffered from a lack of statistical power (Band, van der Molen, & Logan, 2003; Williams et al., 1999), which made it

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impossible to observe developmental trends (see also Urben et al., 2011). In addition, the results of the present study demonstrated developmental trends for the SSRT measured with the different types of material, providing further evidence of development of response inhibition abilities independently of the material used to measure these abilities. The developmental trends observed could be interpreted in line with the horse-race model of Logan and Cowan (1984), which proposed that the act of stopping (i.e., response inhibition) in the stop signal paradigm could be best understood in terms of the interaction between a high order executive system that forms intentions and memory of changing goals, and a subordinate system that executes the commands of the high-order executive system. So, when the stop signal is presented, the execution of the response goal ("go") is replaced by an inhibition of the response goal ("stop") and therefore the ongoing response is inhibited. One could easily imagine that during development, the interaction between the systems becomes more efficient and that the children can therefore inhibit their ongoing response more efficiently.

Furthermore, results showed that the emotional context (independent of the valence) modulated response inhibition abilities. Indeed, we demonstrated that both neutral versions (with colored circles and neutral faces) were equal but elicited better performances than the emotional one. The fact that the version with neutral faces did not differ from the version with neutral material in response inhibition performances suggests that it is the emotion processing that interferes with response inhibition, and not just the face processing. These results were consistent with some previous studies of adults and children (e.g., Hare et al., 2005; Lewis et al., 2006; Schulz et al., 2007) but inconsistent with some others involving children (Lewis et al., 2007; Todd et al., 2008). These discrepancies may come from the age groups studied (children aged from 4 to 6 years of age, from 5 to 16, or adult sample) or from a lower number of participants (e.g., N = 18 in Lewis et al., 2007). Furthermore, the interpretation of performances on tasks in some studies (Lewis et al., 2007; Todd et al., 2008) was hampered by a ceiling effect (more than 95% success rate).

This modulation of response inhibition abilities by emotional context could be interpreted in the light of the dual competition model (Pessoa, 2009). This model proposes that emotion recruits part of the shared resources available for effortful mechanisms. In particular, emotion or motivation reorients the allocation of resources available for effortful mechanisms. Thus, because of the common resources shared between executive function and emotion, such a reallocation is proposed not only to impact the target functions but also other mechanisms. For example, Padmala and Pessoa (2010) reported that when participants were rewarded for shorter and more accurate "go" reaction time in a stop signal paradigm, they exhibited impaired response inhibition abilities (measured with longer SSRT). Therefore, when response inhibition was tested in an emotional context, children demonstrated less efficient response inhibition abilities compared to a paradigm with circles or neutral facial expressions due to the recruitment of shared resources by emotion. Furthermore, adopting a neurobiological perspective could help to better understand this result. Indeed, the anterior cingulate cortex could consist of an affective and a cognitive subdivision (Bush et al., 2000), which were reported to be differentially related to other brain structures supporting emotion and cognition processes. Indeed, the affective subdivision was seen to be linked to limbic structures (notably the amygdala) whereas the cognitive subdivision demonstrated a connection with the prefrontal cortex, and more specifically the

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lateral prefrontal cortex and premotor and supplementary motor areas (Devinsky, Morrell, & Vogt, 1995). Consequently, this structure is presumed to allow the functional integration of emotional and cognitive information. In addition, some studies reported that there is a suppression of the affective subdivision during cognitive processing and that there is a suppression of the cognitive subdivision during emotional processing (Bush et al., 2000). Therefore, emotional processing implied a suppression of the cognitive part of the anterior cingulate cortex, altering the efficiency of effortful cognitive control mechanisms.

In addition, results revealed no interaction between age groups and the emotional influence on response inhibition. This result suggests that this modulation of emotional context on response inhibition is constant throughout childhood. Within a neurobiological perspective, the different developmental time-course of the structures and/or functions related to emotional and cognitive processes could explain this stability during childhood. Thus, limbic structures associated with emotional processes seemed to develop earlier (Chugani, Phelps, & Mazzioa, 1987; Nelson, 1994) than the prefrontal cortex (Diamond, 2002), which is associated with effortful abilities. However, recent studies demonstrated an increase in the volume of the amygdala in males (Giedd et al., 1996) or in both males and females (Ostby et al., 2009) until adolescence. In fact, the maturation of the amygdala's volume and changes in its functioning (i.e., emotional skills) are poorly understood (Giedd et al., 2010). Furthermore, the amygdala's function seems to demonstrate few changes during childhood development whereas the functions of the prefrontal cortex change significantly (Lewis & Todd, 2007). Thus, regarding this developmental primacy of the limbic functions, emotion plays an important role in the development of higher order cognition (Fischer, Shaver, & Carnochan, 1990), which is also consistent with a functionalist approach to emotional development where emotions are thought to organize development through their impact on the other psychological processes (e.g., Campos, Mumme, Kermoian, & Campos, 1994). This interpretation makes it possible to better understand why one finds both a stable modulation of effortful control abilities by emotional context, and also developmental improvements in effortful abilities.

Furthermore, our results showed that the emotional valence did not influence the modulation of response inhibition by emotional context. Indeed, both types of emotion (happiness and sadness) were equivalent in their alteration of response inhibition ability. Inconsistent results have been found in the literature regarding the influence of the valence. Other studies found a greater alteration by positive emotion (e.g., Hare et al., 2005; Schulz et al., 2007) or by negative emotion (Lewis et al., 2006), and still others did not find such differences between positive and negative emotion (e.g., Verbruggen & De Houwer, 2007). The discrepancies between the results may come from the paradigm used (Go/No-Go or stop signal) and the methodology used to induce an emotional context (faces with positive or negative expression, gains/losses of points, or interfering affective stimuli). Consistent with our view, the dual competition model (Pessoa, 2009) did not predict a differential influence of emotion as a function of the valence. Indeed, for this model, the level of arousal explained the differentiated modulation of the executive function, but the recruitment of resources remained the same for positive and negative emotion, and therefore effortful abilities were altered in the same way by both types of emotion.

Concerning the influence of the emotional valence on the "go" trials, results showed that the happy faces were identified faster and more accurately than the sad faces. These differences between positive and negative emotion are consistent with those observed in the literature (e.g., Schulz et al., 2007). This advantage for happy faces could be explained by the fact that positive faces induced positive affect (Otta, Lira, Delevati, Cesar, & Pires, 1994), which in turn is related to approach tendencies (Johansson & Ronnberg, 1996). Such an association explains why happy faces were recognized faster than sad faces.

Some limitations of the present study need to be discussed. First, developmental results found in this study may be limited by the use of a cross-sectional study design instead of a longitudinal study design. In addition, information about the emotional reactivity of each child was not gathered. The administration of a questionnaire such as the Children's Behavior Questionnaire (Rothbart, Ahadi, Hershey, & Fisher, 2001) would have been interesting, especially for the subscales assessing emotional reactivity and effortful control. This type of information would have given a better idea of the behavior of the children in real life situations. The present study focused only on laboratory tasks which may limit the generalization of the results. Nevertheless, these possible limitations do not invalidate the present study.

Further studies are warranted in order to explore in detail the bottom-up influence of emotional context on effortful abilities in other age groups. Indeed, it could be interesting to study this influence in adolescent samples, where the stability of the balance between emotion and cognition is submitted to a significant reorganization process (Somerville & Casey, 2010). To sum up, this study demonstrated a clear influence of emotional context on response inhibition. In addition, response inhibition abilities improve during development whereas the bottom-up alteration of emotional context does not change during middle childhood. Finally, although the valence did not have an influence on response inhibition, happy faces were recognized faster than sad faces.

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