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The influence of peripheral emotions on inhibitory control among children

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ABSTRACT

In this study, we investigated the cognitive-emotional interplay by measuring the effects of executive competition (Pessoa, 2013), i.e., how inhibitory control is influenced when emotional information is encountered. Sixty-three children (8 to 9 years of age) participated in an inhibition task (central task) accompanied by happy, sad, or neutral emoticons (displayed in the periphery). Typical interference effects were found in the main task for speed and accuracy, but in general, these effects were not additionally modulated by the peripheral emoticons indicating that processing of the main task exhausted the limited capacity such that interference from the task-irrelevant, peripheral information did not show (Pessoa, 2013). Further analyses revealed that the magnitude of interference effects depended on the order of congruency conditions: when incongruent conditions preceded congruent ones, there was greater interference. This effect was smaller in sad conditions, and particularly so at the beginning of the experiment. These findings suggest that the bottom-up perception of task-irrelevant emotional information influenced the top-down process of inhibitory control among children in the sad condition when processing demands were particularly high. We discuss if the salience and valence of the emotional stimuli as well as task demands are the decisive characteristics that modulate the strength of this relation.

1. Introduction

In the present study, we examine the interaction between bottom-up processing of emotions and top-down processing of inhibitory control among 8- to 9-year-old children. For this purpose, we used an inhibitory control task with peripheral, i.e., task-irrelevant, emotional information to investigate if and how this information influenced top-down inhibition. Inhibitory control is characterized as the capacity to purposely suppress dominant, automatic, or prepotent action tendencies for the benefit of more situation-adapted and goal-appropriate behavior (Carlson, 2005; Drechsler, 2007; Friedman & Miyake, 2004; Garavan et al., 1999; Harnishfeger & Bjorklund, 1994). It is a domain-general, effortful process that is part of a larger set of executive functions, "which are needed when non-routine behaviors are called for" and which are "thought to confer behavioral flexibility and context-dependency to complex behaviors" (Pessoa, 2009, p. 160).

Various stimulus-response compatibility tasks have been designed (see Homack & Riccio, 2004) to assess inhibitory control in both adults and children. For example, the day-night task (Gerstadt et al., 1994; see Montgomery & Koeltzow, 2010 for review) represents a child-appropriate task that is widely used for measuring inhibitory control among 3- to 7-year-olds. In the task, two different cards are presented depicting either a sun or a moon with stars. For the sun, children are instructed to say "day" in the congruent condition, but "night" in the incongruent condition; respectively vice versa for the moon with stars. The uncommon associations in the incongruent conditions require inhibitory control to overcome the dominant and more automatic association between sun—day or moon—night. Performance on the day-night task improved significantly with age (3.5 to 7 years) but yielded a ceiling effect for reaction times (RTs) and accuracy after that age range (cf. Simpson & Riggs, 2005a, 2005b; Wright et al., 2003 for another version of the day-night task).

2. The link between cognitive control and emotion processing

Both traditional explanations of inhibitory control (Norman & Shallice, 1986) and later theories such as the conflict monitoring account, which incorporates a system that monitors conflict during information processing (Botvinick et al., 2001), suggest that solely top-down control is adjusted to resolve perceptual conflicts. Recently, it

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has been noted that conflict monitoring is grounded in reinforcement learning (Aben et al., 2017; Chiu & Egner, 2019 for a review). Particularly, it is believed that control emerges from associative learning processes that are responsible for overseeing processes such as goal representation and attention. The learning perspective of cognitive control argues that cognitive control can be additionally influenced by bottom-up processing of stimuli that have been learned from previous goals or attentional settings (cf. Awh et al., 2012) and thus interprets them as inter-dependent processes.

One way to examine the interplay between top-down and bottom-up processing in cognitive control is by incorporating the processing of emotions into experimental designs (Pessoa, 2017). Bottom-up emotion generation is a stimulus-focused view of emotional processing that refers to "the elicitation of emotion by the presentation of a stimulus that is thought to have simple physical properties that are inherently emotional" (McRae et al., 2012, p. 253–254). Human faces expressing anger and happiness have been viewed as biologically predisposed to negative and positive stimuli, respectively (Bar & Neta, 2007; Öhman & Mineka, 2001). Although emotion and cognition traditionally have been treated as separate processes, there is increasing evidence that they share an intricate relationship (Chiew & Braver, 2011; Damasio, 1994; Dreisbach & Fischer, 2012; Dreisbach & Fischer, 2015; Dreisbach & Goschke, 2004; Goschke & Bolte, 2014; Mueller, 2011; see Pessoa, 2013 for review), which is partly due to the same brain areas being involved in both emotion and cognition (e.g., amygdala, medial prefrontal cortex; see Pessoa, 2013 for review). Part of this relationship is also evident from the fact that the activation and access of emotion is an automatic and unconscious procedure (Bargh, 1997; Pessoa, 2013).

According to Pessoa's conceptual framework, the dual competition model, visual perception and executive functions are considered capacity-limited processes and share mental resources; therefore, handling perceptual conflict may complicate dealing with inhibition at the same time (e.g., Pessoa, 2013). At the perceptual level, items with emotional content are thought to divert processing resources, increase salience and thereby influence task performance. Although processing of emotion-laden stimuli is prioritized in many ways, it is not independent of attention, but depends on resources in many contexts. In other words, emotion processing is linked to cognition since the manipulation of the one interferes with performance in the other and vice versa (Pessoa, 2013).

At the level of executive function, high-arousal information (e.g., threat) typically causes behavioral interference due to competition for resources, however with the strength of the impact depending on available resources, i.e., when task demands are high, fewer resources are available and interference effects from irrelevant emotional information will be eliminated. In this line of thought, "capacity sharing" (Pessoa, 2009, p. 160) leads to executive competition for resources, a term which refers to the way executive functions such as inhibition are influenced when emotional information is encountered.

From a developmental perspective, emotion and cognitive control are linked, too. As children get older, their inhibitory control (Christ et al., 2001; Wright et al., 2003) and executive functions in general improve (Archibald & Kerns, 1999; Best & Miller, 2010); both are likely linked to the maturation of the prefrontal cortex (Diamond, 2002; Durston et al., 2002; Spencer-Smith & Anderson, 2009). Inhibitory control is a central skill since it is a significant predictor for later school success, social behavior, and academic achievement (Allan et al., 2014; Anderson & Reidy, 2012; Blair & Razza, 2007; Bull et al., 2008), but is also related to cognitive emotion regulation, the ability to intentionally generate, enhance, reduce, or stop a given emotion (Langner et al., 2018). Several studies have argued that children's executive functions mediate cognitive emotion regulation (Hofmann et al., 2012; Schmeichel & Tang, 2015; Teper et al., 2013) and that there is a typical developmental trend for cognitive emotion regulation that is also linked to children's self-control abilities (Carlson & Wang, 2007; Rothbart & Rueda, 2005).

The influence of emotion on cognitive control is relatively task-specific: It depends on the type of affect, positive or negative, the presence of emotions in the task, focal (task-relevant) or peripheral (task-irrelevant; see Goschke & Bolte, 2014 for a review), and the order of congruency in the task. We discuss these parameters in the sections below.

3. Negative versus positive emotion

Positive affect is argued to provide an environment propagating "freedom to explore" (Clore & Gasper, 2000) and facilitates information processing on tasks which require creativity, flexibility, and novel thinking (Ashby & Isen, 1999; Isen, 2008). Some studies have shown that basic emotional interference can be detected as early as 4 years of age (Tottenham et al., 2011). Positive emotions increase cognitive flexibility in production of unique responses (Russ & Schafer, 2006) and verbal generation and (math) problem-solving (Bryan & Bryan, 1991; Greene & Noice, 1988; Qu & Zelazo, 2007). However, positive emotions can also be distracting because they can enhance the scope of attention (Rowe et al., 2007) and result in a lack of attention to detail for both children (Gable & Harmon-Jones, 2010; Schnall et al., 2008; Stifter et al., 2020) and adults (Goschke & Bolte, 2014).

Findings regarding the impact of negative affect on cognitive performance are as well controversial. Although some previous studies have found that negative emotions impair cognitive control (Houwer & Tibboel, 2010; Padmala et al., 2011; Verbruggen & De Houwer, 2007), others have reported the opposite (Öhman et al., 2001; van Steenbergen et al., 2011). Recent fMRI studies replicate these inconsistent findings. Jasinska et al. (2012) examined the effects of peripherally presented threat and reward distracters on behavioral performance and the neural correlates of cognitive control among adults aged 20–31. The results showed that both threat and reward distracters significantly hampered RTs for incongruent trials compared to conditions without distracters. At the neural level, threat distracters significantly decreased activity in regions associated with cognitive control on incongruent trials but significantly increased activity in these same areas on congruent trials. An important aspect in research on emotional processing and cognitive control is that the amount of cognitive demand influences these effects. In an fMRI-study with adults, Papazacharias et al. (2015) investigated the impact of task-irrelevant negative emotions (fearful faces presented shortly before each item) on the performance in an inhibitory control task with conditions varying in levels of attentional control (i.e., low, medium, and high). Negative emotions affected attentional processing differently depending on the cognitive load: Compared to the neutral condition, there were slower RTs when cognitive load was low, faster RTs when cognitive load was intermediate, and no effect when it was high. Papazacharias et al. argued that negative emotions facilitated processing, but this effect disappears in high cognitive load condition because cognitive resources are exhausted. Taken together, these findings indicate that emotion processing influences inhibition, but the direction of this effect remains unclear due to inconsistent findings.

4. Focal versus peripheral emotion

Only a few studies have specifically examined the role of emotional presence, i.e., peripheral, focal or absent emotions, in cognitive control in children (Kramer et al., 2015; Lagattuta & Kramer, 2017). Lagattuta et al. (2011) designed the happy-sad task (see also Bluell & Montgomery, 2014; Song et al., 2017) to extend the application of the day-night task beyond the age of 7 years. In the happy-sad task, children are presented with two focal emotional stimuli, namely happy or sad cartoon faces, printed on cards. When they see a happy face, they are required to say "happy" in the congruent, but "sad" in the incongruent condition, respectively, and vice versa when seeing sad faces. Results showed that the happy-sad task led to increased error rates and longer RTs compared to the emotionally neutral day-night task in both young children and adults. The greater amount of difficulty in the happy-sad task is claimed to be caused by the presence of emotion and likely attributed to interference from emotional stimuli processing with inhibitory control (for similar results, see Ikeda et al., 2014).

Kramer et al. (2015) also compared several stimulus-response-compatibility tasks: e.g., the happy-sad task with focal emotions (task-relevant) and the boy-girl task with peripheral (task-irrelevant) emotions in a sample of 4–11-year-olds and adults. Both tasks were based on the same set of stimuli, i.e., photographs of emotion faces, but for the first, participants had to attend to emotion whereas in the second only to gender. The results revealed that for both children and adults, focal emotions impaired the ability to inhibit prepotent responses more than peripheral emotions (more errors, longer RTs). In an additional experimental manipulation, Kramer et al. (2015) compared performance on boy-girl sad and boy-girl happy (i.e., the card set contained only one emotion); contrary to their assumption boy-girl sad would be more difficult due to the continuous presence of the negative emotion, the results on both tasks did not show any differential influence of emotion in this set-up questioning the impact of sad stimuli in quick succession. However, care must be taken when interpreting the results of this study given that Kramer et al. examined RTs in a cumulative fashion.

In an eye-tracking study, Lagattuta and Kramer (2017) examined 4–10-year-olds' and adults' visual attention to negative and neutral faces which were accompanied by happy faces in two experimental conditions. In one condition, they were asked to "look at the faces" (i.e., free viewing) and in the other, to "look only at the happy faces" (i.e., directed viewing). The results revealed that in both conditions, children and adults more frequently looked at negative faces before positive faces, suggesting that initial visual orientation was driven by bottom-up processes. However, the experimental condition (i.e., top-down instruction) modulated the sustained attention for both groups. During free viewing, both children and adults showed a negativity bias that reduced with age. Contrarily, in the directed viewing condition, both age groups displayed a positivity bias, although this ability weakened over time and significantly more so for children. Post-hoc analyses by Lagattuta and Kramer explored whether the additional cognitive effort in the directed viewing condition influenced participants' attention biases over the course of the experiment. In the free viewing condition, negative attention biases remained stable throughout the trials for both children and adults. In the directed viewing condition, in contrast, the continuous demanding goal to "only look at the happy faces" apparently created additional cognitive demands and led to progressive fatigue in implementing this top-down goal. The authors argued that, as this effect was larger for children compared to adults, the ability to control these concurrent processes improves with age.

These studies indicate the interference of emotion-laden focal information on inhibitory processing in children, whereas emotion-laden peripheral information led to weaker effects on task performance and little impact on behavioral findings (Kramer et al.'s (2015) study). Depending on task requirements (e.g., different viewing conditions), a possible differential influence of positive and negative affect on inhibitory control could be observed, e.g. revealed as attention biases in Lagattuta and Kramer's (2017) study.

5. Congruency sequence

There are several studies that have shown a congruency sequence effect (also referred to as Gratton effect) in tasks examining inhibitory control (e.g., Stroop, Flanker, Simon) in adults (see Egner, 2007) and children (Erb & Marcovitch, 2018). Many of these studies employ an inhibition task in which congruency sequence effects persisting to subsequent trials are interpreted as evidence for conflict-driven cognitive control (Egner et al., 2008; Egner & Hirsch, 2005; Etkin et al., 2006; Kerns et al., 2004). When controlling for feature integration, there are significantly larger congruency sequence effects that emerge more rapidly than conflict adaptation (Notebaert et al., 2006). The sensitivity for trial sequence has been reported in experimental blocks that include trials of alternating congruency. It is unclear, however, as to whether this effect is observed in a blocked design and particularly when examining emotion processing and inhibitory control in children.

6. Present study

Until now, it remains unclear how emotions modulate inhibitory control in children (i.e., "executive competition", Pessoa, 2013) since research findings have been controversial. Therefore, we investigate the impact of bottom-up perception of peripheral emotional information (happy, sad) on top-down inhibitory control. We chose to examine a group of third-graders (typically between ages 8 to 9 years) because important improvements in EF take place between the age of 6 to 13 years (Brocki & Bohlin, 2004; De Cat et al., 2018; Diamond, 2002) and examining this age group can contribute to our understanding of EF development.

For the central task, we designed a computerized version of a child-appropriate inhibitory control task (cf., Ikeda et al., 2014) in which congruency (congruent, incongruent) was manipulated per block. The emotional information (happy, sad) was displayed in the periphery and entirely task-irrelevant. This allowed us to determine the emotion-cognition interplay in a more subtle way and is therefore the strength of the current design. We also included a neutral emotional expression as a neutral baseline and used an increased number of trials compared to previous studies on the interplay of emotion and cognition (e.g., Kramer et al., 2015; Nakagawa et al., 2015). In contrast to Kramer et al. (2015), we analyzed RTs of single trials and counterbalanced the order of congruent and incongruent blocks to manipulate cognitive load and to investigate if congruency sequence effects also emerge in a blocked design.

1) We hypothesize that an interference effect in the central task will emerge for both accuracy and RTs.
2) If peripheral emotional information does not affect inhibitory control due to processing resources being exhausted by the demands of the central task (Pessoa, 2013), no observable difference between the emotional conditions should be found (Ikeda et al., 2014; Kramer et al., 2015).

   With regard to a possible impact of different emotional information, we expect a larger interference effect in the positive condition compared to the neutral condition if positive affect facilitates flexibility at the expense of increased distractibility resulting in difficulties to focus on the color embedded in the stimulus. By contrast, if bottom-up perception of emotional information in the periphery leads to negative bias (cf., Lagattuta & Kramer, 2017) and negative affect narrows the focus of attention, participants would likely focus only on the central task. Thus, there should be smaller interference effects for the negative conditions compared to the neutral conditions.
3) If the order of congruency blocks (congruent-incongruent, C-I, vs. incongruent-congruent, I-C) affects the current blocked design in the same way as has been shown for trial-by-trial analyses (cf. Egner, 2007), we expect the interference effect to be larger in blocks beginning with C-I compared to blocks starting with I-C.

7. Method

7.1. Participants

One hundred primary school children in 3rd grade took part in this study. We excluded children whose IQ indicated an intellectual disability (i.e., IQ < 70; $n = 2$ children) what was assessed with the Culture Fair Intelligence Test Scale 1 (CFT 1-R, Weiß & Osterland, 2013). Additionally, multilingual children were excluded, since multilingualism can influence executive functions ($n = 37$ children; based on information from a parental questionnaire; (Czapka et al., 2019). The final sample included 63 children from three different primary schools (32 males, 31 female) who were on average 106.7 months old (SD = 5.1; range: 97–121) and had intelligence values within a normal range (t-value; M = 52.0, SD = 8.4). All children had normal or corrected-to-normal vision, were naive to our research objectives in the study, and received stickers for their participation. The study was approved by the University of Potsdam Ethics Committee, the head of the schools, the Ministry of Education, Youth and Health (Land Brandenburg), and the Senate for Education, Youth and Science (Berlin) and was conducted in accordance with the Declaration of Helsinki. Parents gave written informed consent for their children's participation.

7.2. Inhibitory control task

The inhibitory control task (central task) required children to respond to the nose color of a yellow emoticon presented at the center of a black touch screen (see Fig. 1). This target stimulus was a colored oval (blue or white) depicting the "nose" of the emoticon. Participants were asked to press the button in the same color in congruent blocks (e.g., blue "nose" – blue button), but the opposite color-button (e.g., blue "nose" – white button) in the incongruent condition. The buttons were located at the opposite corners at the bottom of the screen (see Fig. 1) and the arrangement was counterbalanced such that for half of the participants the white button was on the left and the blue button was on the right corner, and for the other half, the blue corner was left and the white one was right. Before each trial, a fixation cross (4 × 4 cm) was presented for 500 ms followed by the stimulus (i.e., the emoticon 6 cm in diameter with the colored nose 1.5 cm in diameter) that appeared until a response was given or until 2500 ms. Participants responded by tapping on one of two colored buttons (5.2 × 3.5 cm) at the lower left/right side of the touch screen with a pen. Afterwards a blank screen was displayed until the participant pressed the orange "home-button" (2.5 × 2.5 cm) in the lower center of the touch display. This button was introduced so that participants could not stay on either side of the tablet after responding to a given stimulus, since this would influence the RT on the next trial. After 500 ms, the next trial began.

To test the impact of emotional information presented in the periphery, we used three conditions by manipulating the emoticon: happy, neutral, and sad (see Fig. 2). In each of the three conditions, participants were instructed to respond exclusively to the color of the "nose" ignoring whether the emoticon expressed an emotion (i.e., happy or sad) or not (i.e., neutral). The entire experiment consisted of 6 blocks with 30 trials each (15 blue and 15 white "noses"): one block for each congruency and emotion (i.e., sad/congruent, sad/incongruent, neutral/congruent, neutral/incongruent, happy/congruent, and happy/incongruent). We chose to present consecutive blocks with the same emotion to create longer-lasting emotional manipulations as they are more age-appropriate and more intense than brief presentations with trial-by-trial changes. Congruency conditions were presented alternatingly. Consequently, six different versions were created (every possible order of emotion and both congruency sequences, C-I and I-C) to counterbalance order of congruency and emotional conditions across participants.

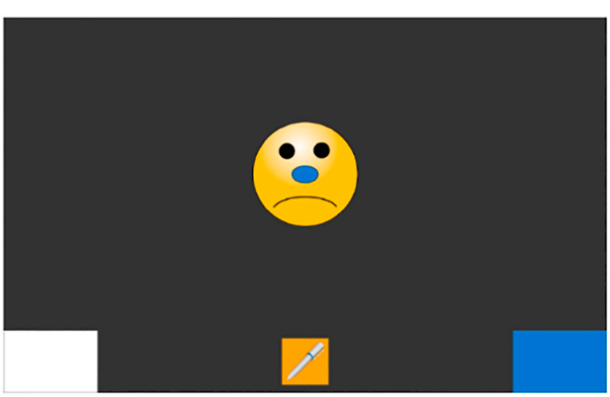

Fig. 1. Example of an experimental trial. In a congruent condition, the participant needs to tap on the blue corner button with the pen and then to move back to the orange "home-button" in the lower center of the screen and to tap on it. In the sad incongruent condition, the participant is required to tap on the white corner button, then on the orange button. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

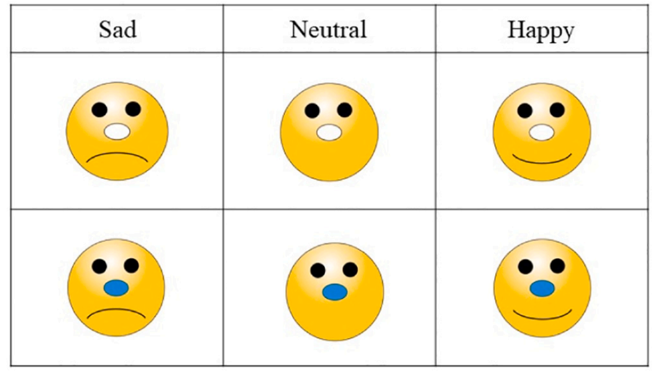

Fig. 2. Six stimuli used in the test including two color-noses (white or blue) and three emoticon-emotional states. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

7.3. Procedure

Participants were seated in front of a tablet computer (i.e., Microsoft Surface Pro 2; 1920 × 1080 pixel; using Microsoft Visual Studio) in a quiet classroom where 10 to 12 children at a time completed the task. The instruction phase (about 5 min) included presentation of the stimuli with their assignments to response buttons according to the congruency and the task itself. Then participants were asked to take the Surface Pro 2 pen with their writing hand while placing the other hand next to the tablet. Training consisted of six trials (each colored "nose" presented once on each emoticon; refer back to Fig. 2) for which feedback was provided. After the instruction phase, the experimental phase began. The entire session took approximately 30 min.

7.4. Data pre-processing and statistical analyses

Blocks with a below chance performance (i.e., 50%) were excluded ($n = 2$). Only RTs from correct trials were analyzed and log-transformed to normalize distribution. Outliers in the form of single data points that were 2 SD above or below a participant's mean RT ($n = 488$ what corresponds to 4.3% of all data points) were removed. Performance in terms of percentage of correct answers was very high, in particular in the congruent condition. As such, detailed analyses included only RTs, but differences between emotion and congruency conditions in terms of accuracy were analyzed using linear regression models including main effects for CONGRUENCY and EMOTION and their interaction.

All analyses were run using R (R Core Team, 2015). RTs were analyzed in stepwise linear mixed regression models (with the lme4 package; Bates et al., 2014) that assessed in the first step the congruency effect (fixed effect for CONGRUENCY; congruent coded as 0, incongruent coded as 1). In the next step, we added and examined fixed effects for EMOTION (neutral coded as 0, happy and sad coded as 1) including main effects and interaction with CONGRUENCY. Model fit was compared with an ANOVA. In a last step, other predictors for executive functions (i.e., age, intelligence, and gender) were added. In all models, a maximally complex random effects structure with varying intercepts for subjects and varying slopes for CONGRUENCY and EMOTION was fit. More parsimonious random effects structures without random slopes for CONGRUENCY or EMOTION did not improve model fit (Bates et al., 2015).

In a planned post-hoc analysis investigating the interference effect and the order of the congruency conditions (CONGRUENCY SEQUENCE: C-I – congruent-incongruent; I-C – incongruent-congruent), a linear mixed effects model with a varying intercept for subject was computed to calculate the effect of CONGRUENCY SEQUENCE and EMOTION on the size of the interference effect.

8. Results

8.1. Main Analyses

Performance in each emotion and congruency condition in terms of accuracy and RTs is displayed in Table 1. As performance in terms of accuracy was at ceiling, we did not analyse accuracy in detail. Still, linear regression models predicting the percentage of correct answers and errors revealed a significant congruency effect (correct: b = −7.2, SD = 1.3, $t = -5.4$, $p < .001$; errors: $b = 5.9$, $SD = 0.9$, $t = 6.5$, $p < .001$). For correct answers, the intercept varied significantly ($b = 95.2$, $SD = 0.9$, $t = 101.8$, $p < .001$) but not for the percentage of errors ($b = 1.1$, $SD = 0.6$, $t = 1.7$, $p > .05$). No influence of emotion (correct: happy vs. neutral $b = -0.5$, $SD = 1.3$, $t = -0.4$, $p > .05$; sad vs. neutral $b = -0.6$, $SD = 1.3$, $t = -0.4$, $p > .05$; errors: happy vs. neutral $b = 0.0$, $SD = 0.9$, $t = 0.0$, $p > .05$; sad vs. neutral $b = 0.0$, $SD = 0.9$, $t = 0.1$, $p > .05$) nor an interaction of congruency and emotion was found for either measure (correct: incongruent x happy $b = 1.8$, $SD = 1.9$, $t = 1.0$, $p > .05$; incongruent x sad $b = 1.0$, $SD = 1.9$, $t = 0.5$, $p > .05$; errors: incongruent x happy $b = -1.2$, $SD = 1.3$, $t = -0.9$, $p > .05$; incongruent x sad $b = -0.5$, $SD = 1.3$, $t = -0.4$, $p > .05$). For missing responses, the intercept varied significantly ($b = 3.7$, $SD = 0.7$, $t = 5.2$, $p < .001$) but no influence of congruency or emotion was found (incongruent: $b = 1.3$, $SD = 1.0$, $t = 1.3$, $p > .05$, happy: $b = 0.5$, $SD = 1.0$, $t = 0.5$, $p > .05$; sad: $b = 0.6$, $SD = 1.0$, $t = 0.5$, $p > .05$; incongruent x happy: $b = -0.7$, $SD = 1.4$, $t = -0.5$, $p > .05$; incongruent x sad: $b = -0.5$, $SD = 1.4$, $t = -0.4$, $p > .05$).

The stepwise regression model predicting log-transformed RTs included initially only a fixed effect for CONGRUENCY and fit the data best (regression coefficients for all models are displayed in Table A1 in the Appendix). This model included a significantly varying intercept (corresponding to the mean for the congruent condition; $b = 6.87$, SE = 0.01, $t = 590.1$) and a significant effect of CONGRUENCY ($b = 0.23$, SE = 0.01, $t = 24.7$), indicating that RTs in the incongruent condition were significantly higher than in the congruent condition. Neither adding fixed effects for EMOTION, the interaction EMOTION and CONGRUENCY, nor adding the background variables AGE, GENDER, and INTELLIGENCE to the congruency-only model improved the model fit (Model 2: $\chi^2 = 3.10$, $p = .5$; Model 3: $\chi^2 = 1.03$, $p = .6$; Model 4: $\chi^2 = 5.58$, $p = .13$, respectively). Fig. 3 displays the RT results per emotional condition (neutral, happy, sad) for congruent and incongruent blocks and illustrates the overall congruency effect irrespective of emotional condition.

Table 1
Descriptive statistics by emotional condition and congruency: percentage of correct, missing, or incorrect responses (in %), and mean and standard deviation (SD) of RTs.

Emotion	Congruency	Correct	Missing	Incorrect	RT (SD)
Neutral	Congruent	95.2	3.7	1.1	988 (134)
Neutral	Incongruent	88.0	5.0	7.0	1238 (153)
Happy	Congruent	94.7	4.2	1.1	998 (119)
Happy	Incongruent	89.3	4.9	5.8	1257 (170)
Sad	Congruent	94.6	4.3	1.1	998 (98)
Sad	Incongruent	88.3	5.1	6.6	1242 (124)

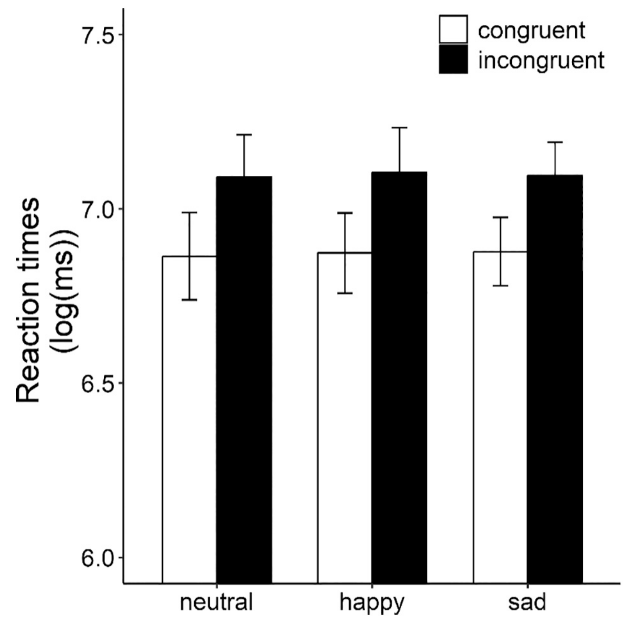

Fig. 3. Reaction times (RT, log-transformed, error bars display standard errors) for congruency (central task) according to emotion conditions (peripheral task).

8.2. Post-hoc analyses

In follow-up analyses, we investigated if emotions affected RTs differently over the course of the experiment. This was motivated by our knowledge of the impact of congruency order on performance in inhibition tasks (Egner, 2007; Erb & Marcovitch, 2018), which is why we counter-balanced the order of congruency in this experiment, and reinforced by the insignificant effect of emotion in the previous analysis. Since congruency influenced RTs in all conditions, we used the interference effect (RT difference between congruent and incongruent conditions) as the dependent variable. We calculated the interference effect in combination with congruency sequences (i.e., the order of

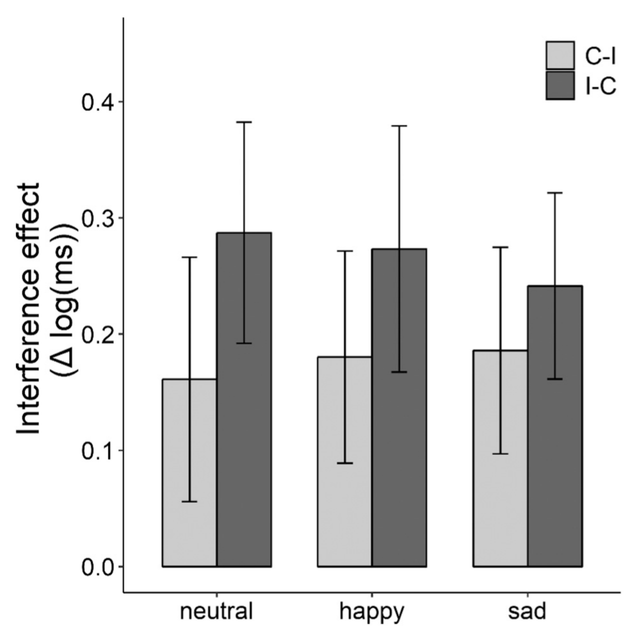

Fig. 4. Interference effects (IE, log-transformed, error bars display standard errors) for congruency sequences (C-I = congruent block followed by an incongruent block; I-C = incongruent-congruent) according to emotion conditions (peripheral task).

congruency conditions) and found a subtle influence of emotion (see Fig. 4).

Table 2 displays the linear mixed effects model predicting the size of the interference effect with ORDER and EMOTION as predictors. The model shows a significantly varying intercept for subject and a significant effect for ORDER ($b = 0.13$, SE = 0.02, $t = 5.22$) indicating that the interference effect was larger when incongruent blocks preceded congruent ones. It also yielded a significantly lower impact of order in the sad condition ($b = -0.07$, SE = 0.03, $t = -2.12$). t-Tests revealed that CONGRUENCY SEQUENCE influenced the size of the interference effect significantly in all three EMOTION conditions, with a large effect size in the neutral condition (C-I: M = 0.16, SD = 0.11, I-C: M = 0.29, SD = 0.1, $t(56.97) = -4.93$, $p < .001$, $d = -1.26$) and happy condition (C-I: M = 0.18, SD = 0.09, I-C: M = 0.27, SD = 0.11, $t(60.99) = -3.75$, $p < .001$, $d = -0.94$) and a medium effect size in the sad condition (C-I: M = 0.19, SD = 0.09, I-C: M = 0.24, SD = 0.08, $t(56.93) = -2.58$, $p < .05$, $d = -0.66$).

To unravel the origin of the congruency sequence effect, we examined whether it changed over the course of the experiment. To do so, we calculated linear regression models predicting the interference effect with the same factors (CONGRUENCY SEQUENCE and EMOTION) but for each set of congruent-incongruent conditions separately. Given that congruency conditions were presented alternatingly, the experiment consisted of three sets that were assigned to one of the emotion conditions (see Fig. 5). Here, we report only significant effects, but the complete models can be found in Table A2 in the Appendix. There was significant variance in intercepts (first set: $b = 0.16$, SE = 0.03, $t = 5.19$, $p < .001$; second set: $b = 0.18$, SE = 0.03, $t = 6.47$, $p < .001$; third set: $b = 0.15$, SE = 0.03, $t = 5.16$, $p < .001$) and a significant effect of ORDER in every set (first set: $b = 0.22$, SE = 0.04, $t = 5.17$, $p < .001$; second set: $b = 008$, SE = 0.04, $t = 2.18$, $p < .05$; third set: $b = 0.1$, SE = 0.04, $t = 2.42$, $p < .05$), implying that the interference effect was larger when the incongruent preceded the congruent condition compared to the opposite order. Although there were no significant main effects for EMOTION, the interaction between CONGRUENCY SEQUENCE and EMOTION, i.e., sad compared to neutral, reached statistical significance, but only in the first set ($b = -0.17$, SE = 0.06, $t = -3.09$, $p < .01$). This effect indicated that the interference effect in the first set in the I-C sequence was smaller in the sad compared to the neutral condition (see also Fig. 5).

Pairwise t-tests (see Table 3) revealed that the sad condition was the only one in which RTs were relatively stable throughout the experiment (i.e., RTs of the first block were not significantly different from the other blocks taken together). In all other conditions, RTs were initially longer and became shorter. As can be also seen in Fig. 5, only at the beginning of the experiment (i.e., in the first set), the difference between C-I and I-C was smaller in the sad than in the neutral condition.

9. Discussion

In the present study, we investigated the impact of task-irrelevant peripheral emotions on inhibitory control in 3rd graders. We presented happy, neutral, and sad emoticons in an age-appropriate computerized inhibitory control task allowing for within-task differentiation of emotional expressions on inhibitory control processes ("executive competition", Pessoa, 2013). First of all, we found a reliable interference effect in the RTs and number of correct answers, with incongruent blocks leading to slower RTs and less correct answers than congruent blocks. No general influence of peripheral emotion was found. That said, in post-hoc analyses, we found that a) the size of the interference effect depended on the congruency sequence order with incongruent preceding congruent conditions leading to a larger interference effect and that b) this difference was reduced in the sad condition, especially at the beginning of the experiment, yielding evidence of distinct modulations of the impact of task-irrelevant emotional information.

Table 2
Fixed effects of the regression model including congruency sequence and emotion predicting the interference effect.

	b	SE	t
(Intercept)	0.16	0.02	9.14
I-C	0.13	0.02	5.22
Happy	0.02	0.02	0.80
Sad	0.02	0.02	1.03
I-C: happy	−0.03	0.03	−1.00
I-C: sad	−0.07	0.03	−2.12

9.1. Top-down inhibitory control

The interference effect observed in the present study is in line with a long history of studies using stimulus-response compatibility tasks showing that in the present manipulation (color of the "nose") the incongruent blocks were more demanding than congruent ones (slower RTs and more errors; e.g., Gerstadt et al., 1994). In this newly designed task, the setup of the central task was successful since the nose as the relevant stimulus triggered the color identification as the prepotent reaction (i.e., associative learning). Task performance was relatively easy on congruent trials (color congruency) but more difficult for the participating children on incongruent trials. In these latter, more demanding trials, after identification of the nose color, children needed to inhibit the general color congruency (i.e., tapping on the matching color button) and choose the competing subdominant response in this two-response set (i.e., the other color button in the other corner of the tablet). The results also indicated that top-down inhibitory control was flexible as it was executed according to block-wise changing task demands (congruent or incongruent block) and that the participants could adapt inhibitory control to the degree of conflict in the block. Beyond the necessary inhibitory control required for executing the central task, more general cognitive control was necessary to master the perceptual conflict inherent in the emoticon stimulus (central and peripheral information): The focus of attention on the central task was necessary for successful task performance. It can be assumed that the children in our study were well able to prioritize the information of the central task and to focus their attention on allocating resources to process the color stimuli according to task demands. The high percentage of correct responses shows overall successful task performance which indicates focus on the relevant stimulus and underlying appropriate general cognitive control.

9.2. The influence of congruency sequence

In the literature congruency sequencing effects are commonly tested on a trial-by-trial basis and indicate a smaller interference effect for a congruent following an incongruent trial as compared to the opposite (Egner, 2007). In our study using a blocked design, the opposite pattern emerged: the interference effect was larger when a congruent block followed an incongruent one. This could be explained based on differential monitoring demands in blockwise and trial-by-trial conditions: The blockwise-changing demands might require the participants to rely on sustained proactive control as compared to the fluctuating monitoring demands in trialwise-changing designs that might require reactive control (for the dual mechanisms of control model, see Braver, 2012). Given that proactive control emerges between 5 and 7 years (Munakata et al., 2012), children in our age-group were most likely able to anticipate incongruency in the incongruent block as they seemed to prevent interference in the upcoming trials quite successfully by relying on proactive control (rather than on reactive control; Braver, 2012). This more demanding incongruent condition leads to slower RTs. In the following congruent block, the task can be perceived as easier (compared to the previous block) what allows participants to speed up. This leads to a magnified interference effect compared to the sequence order with increasing difficulty (i.e., congruent followed by incongruent

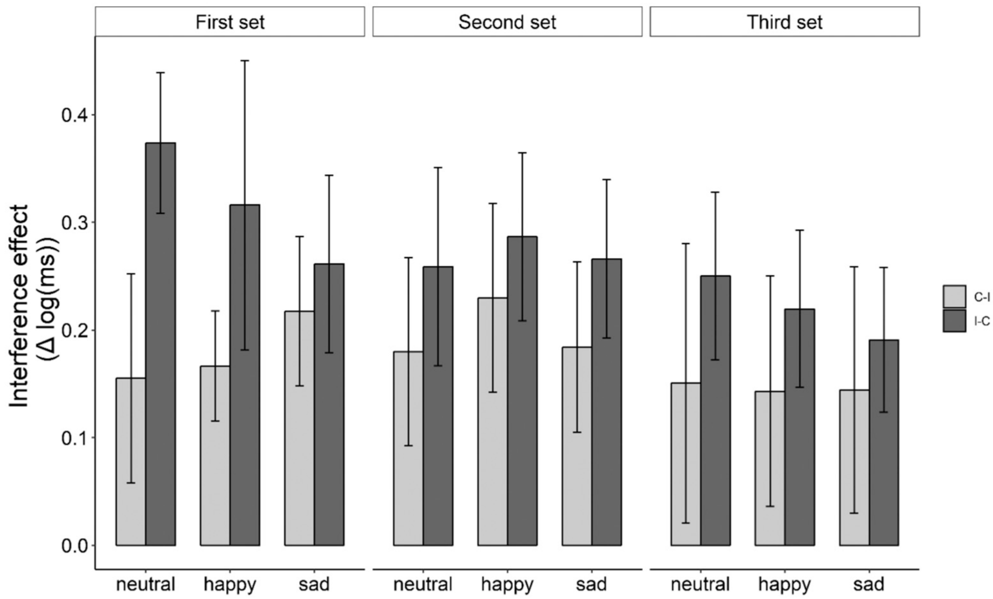

Fig. 5. Interference effect (IE, log-transformed, error bars display standard errors) for emotion conditions and congruency sequence with C-I (light grey) (i.e., congruent preceded incongruent block), and I-C (dark grey) (i.e., incongruent before congruent block) split by set (i.e., pair of congruent and incongruent blocks).

Table 3
Mean RTs (in ms) per experimental block (1 to 6) for version and congruency, and *p*-values for pairwise comparisons between first and subsequent blocks.

Version	Congruency	1	2	3	4	5	6	*p* Block 1 vs. blocks 2–6
Neutral	Congruent	1034	995	1011	978	996	908	<.001
Neutral	Incongruent	1440	1212	1255	1203	1165	1157	<.001
Happy	Congruent	1048	985	1040	951	998	961	<.001
Happy	Incongruent	1353	1237	1273	1316	1190	1147	<.001
Sad	Congruent	1044	976	970	966	1037	993	<.001
Sad	Incongruent	1265	1309	1258	1176	1223	1199	.12

block).

9.3. The influence of task-irrelevant emotions on inhibitory control

Unlike the happy-sad tasks reported in Ikeda et al. (2014) and Lagattuta et al. (2011), emotional information was only displayed at the periphery and it was not relevant for performing the task in the present study. Thus, there were no emotional properties in the central stimulus itself (i.e., a colored nose rather than emotion words or angry faces) and no emotional responses had to be given. At the level of a general analysis of accuracy and RTs, the emotional distracter in the periphery did not yield any modulation of speed or accuracy in either emotion condition in our study.

This might be surprising as emotional stimuli have been found to interfere with performance even when they were task-irrelevant (see e.g., Pessoa & Ungerleider, 2004; Vuilleumier, 2005) and even when the central task is quite basic (Pereira et al., 2010). Even irrelevant stimuli are thought to capture unintentionally resources that enable their processing, if the relevant, central task does not demand all the available attentional resources (Pessoa, 2013). What follows from this is that when cognitive demands are high for performing on the central task, fewer resources are available for the peripheral information and interference effects from the irrelevant information could be eliminated. This means that responses to peripheral emotional stimuli depend on the availability of resources (De Cesarei et al., 2009). The lack of the CONGRUENCY X EMOTION interaction might be related to participants investing more effort (or attention) in the central task trials and thus were not able to process the emotional information enough to enable its effect on performance. In contrast, focal presentation of emotion in Kramer et al. (2015) did impair children's inhibitory control; in Lagattuta and Kramer (2017), the task instruction induced bottom-up processing of emotional information (i.e., look at faces) and led to a negative bias when contrasted with a general bottom-up perception in the happy-sad task (and see Song et al., 2017 describing the impact of task-relevant mild and intense emotional conflict on inhibitory control in adults).

However, emotional information in the periphery is still assumed to be processed automatically (Pessoa, 2013). But when arousal is low and the emotional information is task-irrelevant, despite interference of the main task being observed, the behavioral effects are small. This is why only our fine-grained analyses revealed a small effect of emotion, and only at the beginning of the experiment: In contrast to the neutral condition, the congruency sequence effect in the sad condition was smaller. This effect was caused by lower RTs in the sad, incongruent block at the beginning of the experiment (I-C order). Thus, the fact that the interference effect varied as a function of emotion provides first evidence that peripheral emotional expressions influence inhibitory control processes - at least at the beginning of this type of task. More precisely, the participants' RTs in the incongruent, sad block when presented first in the experiment were already as fast as the RTs in subsequent blocks, whereas RTs in the other two congruency-emotion conditions were initially slower than in the rest of the experiment. The results for the neutral and positive condition seem to reflect the *default-mode* of interference control, i.e., decreasing RTs with continuous training. The results for the negative condition, however, may indicate a *context-driven change* in performance (see further below for more detail).

In contrast to our study, other studies found a general impact of peripherally-presented emotions on inhibition, but two contextual factors seem to determine the relation between emotion processing and inhibitory control: salience of the emotion distractors and cognitive task demands. For example, emotional distractors in Jasinska et al. (2012) influenced performance as both negative and positive distractors in their study slowed down RTs. The reason may be different perceptual salience of the emotional information: In their study the items (three digits) were flanked on both sides by large, colorful pictures of either humans expressing intense negative emotions (fear distractor) or highly attractive food stimuli (reward distractor). For the emotional information in our study, in contrast, we used visually less salient stimuli: the mouths of emoticons were only a thin black line, which had the same color and thickness as all lines in the yellow emoticon and were less salient than the target (nose colored in blue or white).

However, the direction of the effect in Jasinska et al.'s study was opposite to ours. Papazacharias et al.'s (2015) results indicate that task demands might modulate the direction of the effect. Papazacharias et al.'s study with adults reported faster responses on incongruent trials with intermediate attentional demands following the presentation of negative emotions. The demands in our task might be at an intermediate level as in Papazacharias et al. since we tested children whose cognitive control is still developing. Additionally, the impact of emotions appeared only at the beginning of the experiment. Cognitive load is commonly higher at the beginning of the experiment (when participants are occupied with associative learning, perceptual conflict, and adaptation of control processes to demands of the current task and block), as indicated by slower responses. Participants in our study not only quickly learned to associate their response in the requested condition (incongruent condition), but as argued above, likely also learned to efficiently associate the stimulus already with specific control needs (i.e., proactive control) and thus were able to adapt their processing speed when executing inhibitory control (lower RTs in all subsequent blocks) —but only in the sad condition. This finding is in line with Lagattuta and Kramer (2017) in which negative/sad emotions cue a focus of attention, even if presented peripherally and with no relevance for the currently executed task. The sharpened focus gained from the experience with the sad condition in our study might have led to enhanced inhibitory control and a small adaptation in behavior (i.e., RTs) throughout the experiment. This is in line with studies that showed that negative emotion might increase conflict adaptation (van Steenbergen et al., 2010) what has been shown in this study for children.

10. Limitations and future studies

In the present study, we could only provide some indication for differences between the neutral condition and the other two emotional conditions. Therefore, behavioral research findings on the impact of task-irrelevant emotional information on inhibitory control remain controversial and future studies need to unveil the impact of salience of emotional distracters and task demands on inhibitory control, including the direction and strength of this relation. Investigations which combine behavioral and neuroimaging methods seem most suitable for providing a better understanding of these factors and their modulating impact. Notwithstanding, future studies should investigate individual differences with regard to the effect of emotions on cognitive processing, in particular on executive competition. For example, in a study on brain and behavioral inhibitory control, Farbiash and Berger (2016) found that some kindergarten children performed worse than others when facing negative emotions.

This study is, to our knowledge, the first that reports congruency-sequence effects in a blocked design. Further studies that compare RTs in a blocked versus a trial-based design might give further insights into the influence of congruency sequence on performance.

11. Conclusion

In the present study, we examined the relationship between bottom-up processing of peripheral emotions and top-down processing of inhibitory control. We did not find a general impact of emotions on inhibitory control, likely due to the reduced salience of our emotional stimuli in comparison to, for example, Jasinska et al. (2012) and the children's efficient and focused handling of the central task. Still, we found that our sad condition led to a smaller interference effect at the beginning of the study related to smaller RTs in the incongruent block if it appeared as initial block. The direction of the relation between emotion and RTs is opposite to other studies with adults like Jasinska et al. (2012). As faster RTs appeared in intermediate but not low cognitively demanding conditions (Papazacharias et al., 2015), we conclude that the cognitive demands likely led to this effect: higher demands at the beginning of the experiment and the fact that we tested children with developing cognitive control abilities explain our results. Our study also extends the findings from Kramer et al. (2015), who examined the impact of peripheral emotion information on inhibitory control in children, by overcoming methodological limitations, i.e., by using a trial-based RT analysis and replicating an effect of sadness on inhibitory control in terms of a reduction of response latencies. The irrelevance of the emotional information displayed at the periphery nonetheless shows the strong automaticity (Pessoa, 2013) of emotional processing when cognitive demands in the central task are high enough. More specifically, due to the inherent warning sign for cautiousness, negative (at least facial) emotional expressions—task-irrelevant and presented in the periphery—seem to narrow children's attention, resulting in improved situation-adapted and goal-appropriate behavior.

Declaration of competing interest

We have no conflicts to declare.

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Appendix A. Supplementary data

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References

Aben, B., Verguts, T., & Van den Bussche, E. (2017). Beyond trial-by-trial adaptation: A quantification of the time scale of cognitive control. *Journal of Experimental Psychology: Human Perception and Performance, 43*(3), 509–517.

Allan, N., Hume, L., Allan, D., Farrington, A., & Lonigan, C. (2014). Relations between inhibitory control and the development of academic skills in preschool and kindergarten: A meta-analysis. *Developmental Psychology, 10*, 2368–2379.

Anderson, P., & Reidy, N. (2012). Assessing executive function in preschoolers. *Neuropsychology Review, 22*, 345–360.

Archibald, S., & Kerns, K. (1999). Identification and description of new tests of executive functioning in children. *Child Neuropsychology, 5*, 115–129.

Ashby, F., & Isen, A. (1999). A neuropsychological theory of positive affect and its influence on cognition. *Psychological Review, 106*(3), 529.

Awh, E., Belopolsky, A., & Theeuwes, J. (2012). Top-down versus bottom-up attentional control: A failed theoretical dichotomy. *Trends in Cognitive Sciences, 16*(8), 437–443.

Bar, M., & Neta, M. (2007). Visual elements of subjective preference modulate amygdala activation. *Neuropsychologia, 45*, 2191–2200.

Bargh, J. (1997). The automaticity of everyday life. In R. Wyer, Jr. (Ed.), *The automaticity of everyday life* (pp. 1–61). New York, NY: Erlbaum.

Bates, D., Kliegl, R., Vasishth, S., & Baayen, H. (2015). Parsimonious mixed models. arXiv preprint. Available at: http://arxiv.org/abs/1506.04967.

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2014). Available at:. In *lme4: Linear mixed-effects models using Eigen and S4* (pp. 1–7) http://cran.r-project.org/package=lme4.

Best, J., & Miller, P. (2010). A developmental perspective on executive function. *Child Development, 81*, 1641–1660.

Blair, C., & Razza, R. (2007). Relating effortful control, executive function, and false belief understanding to emerging math and literacy ability in kindergarten. *Child Development, 78*, 647–663.

Bluell, A., & Montgomery, D. (2014). The influence of stimulus discriminability on young children's interference control in the Stroop-like happy-sad task. *Journal of Cognition and Development, 15*, 437–452.

Botvinick, M., Braver, T., Barch, D., Carter, C., & Cohen, J. (2001). Conflict monitoring and cognitive control. *Psychological Review, 108*(3), 624.

Braver, T. (2012). The variable nature of cognitive control: A dual mechanisms framework. *Trends in Cognitive Sciences, 16*(2), 106–113.

Brocki, K., & Bohlin, G. (2004). Executive functions in children aged 6 to 13: A dimensional and developmental study. *Developmental Neuropsychology, 26*, 571–593.

Bryan, T., & Bryan, J. (1991). Positive mood and math performance. *Journal of Learning Disabilities, 24*(8), 490–494.

Bull, R., Espy, K., & Wiebe, S. (2008). Short-term memory, working memory, and executive functioning in preschoolers: Longitudinal predictors of mathematical achievement at age 7 years. *Developmental Neuropsychology, 33*, 205–228.

Carlson, S. (2005). Developmentally sensitive measures of executive function in preschool children. *Developmental Neuropsychology, 28*, 595–616.

Carlson, S., & Wang, T. (2007). Inhibitory control and emotion regulation in preschool children. *Cognitive Development, 22*, 489–510.

Chiew, K., & Braver, T. (2011). Positive affect versus reward: Emotional and motivational influences on cognitive control. *Frontiers in Psychology, 2*(279).

Chiu, Y.-C., & Egner, T. (2019). Cortical and subcortical contributions to context-control learning. *Neuroscience and Biobehavioral Reviews, 99*, 33–41.

Christ, S., White, D., Mandernach, T., & Keys, B. (2001). Inhibitory control across the life span. *Developmental Neuropsychology, 20*, 653–669.

Clore, G., & Gasper, K. (2000). Feeling is believing: Some affective influences on belief. In N. Frijda, A. Manstead, & S. Bem (Eds.), *Emotions and beliefs: How do emotions influence beliefs?* (pp. 10–44). Cambridge, UK: Cambridge University Press.

Czapka, S., Klassert, A., & Festman, J. (2019). Executive functions and language: Their differential influence on mono- vs. multilingual spelling in primary school. *Frontiers in Psychology, 10*, Article 97.

Damasio, A. (1994). *Descartes' error: Emotion, reason, and the human brain*. New York, NY: Grosset/Putnam.

De Cat, C., Gusnanto, A., & Serratrice, L. (2018). Identifying a threshold for the executive function advantage in bilingual children. *Studies in Second Language Acquisition, 40*(1), 119–151.

De Cesarei, A., Codispoti, M., & Schupp, H. T. (2009). Peripheral vision and preferential emotion processing. *Neuroreport, 20*(16), 1439–1443.

Diamond, A. (2002). Normal development of prefrontal cortex from birth to young adulthood: Cognitive functions, anatomy, and biochemistry. In D. Stuss, & R. Knight (Eds.), *Principles of frontal lobe function* (pp. 466–503). Oxford, England: Oxford University Press.

Drechsler, R. (2007). Exekutive funktionen: Übersicht und taxonomie [Executive functions: Overview and taxonomy]. *Zeitschrift für Neuropsychologie, 18*, 233–248.

Dreisbach, G., & Fischer, R. (2012). Conflicts as aversive signals. *Brain and Cognition, 78*(2), 94–98.

Dreisbach, G., & Fischer, R. (2015). Conflicts as aversive signals for control adaptation. *Current Directions in Psychological Science, 24*(4), 255–260.

Dreisbach, G., & Goschke, T. (2004). How positive affect modulates cognitive control: Reduced perseveration at the cost of increased distractibility. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 30*, 343.

Durston, S., Thomas, K., Yang, Y., Ulug, A., Zimmerman, R., & Casey, B. (2002). A neural basis for the development of inhibitory control. *Developmental Science, 5*, F9–F16.

Egner, T. (2007). Congruency sequence effects and cognitive control. *Cognitive, Affective, & Behavioral Neuroscience, 7*(4), 380–390.

Egner, T., Etkin, A., Gale, S., & Hirsch, J. (2008). Dissociable neural systems resolve conflict from emotional versus nonemotional distracters. *Cerebral Cortex, 18*(6), 1475–1484.

Egner, T., & Hirsch, J. (2005). Cognitive control mechanisms resolve conflict through cortical amplification of task-relevant information. *Nature Neuroscience, 8*, 1784–1790.

Erb, C., & Marcovitch, S. (2018). Deconstructing the gratton effect: Targeting dissociable trial sequence effects in children, pre-adolescents, and adults. *Cognition, 179*, 150–162.

Etkin, A., Egner, T., Peraza, D., Kandel, E., & Hirsch, J. (2006). Resolving emotional conflict: A role for the rostral anterior cingulate cortex in modulating activity in the amygdala. *Neuron, 51*, 871–882.

Farbiash, T., & Berger, A. (2016). Brain and behavioral inhibitory control of kindergartners facing negative emotions. *Developmental Science, 19*(5), 741–756.

Friedman, N., & Miyake, A. (2004). The relations among inhibition and interference control functions: A latent-variable analysis. *Journal of Experimental Psychology General, 133*, 101–135.

Gable, P., & Harmon-Jones, E. (2010). The motivational dimensional model of affect: Implications for breadth of attention, memory, and cognitive categorization. *Cognition and Emotion, 24*, 322–337.

Garavan, H., Ross, T., & Stein, E. (1999). Right hemispheric dominance of inhibitory control: An event-related functional MRI study. *Proceedings of the National Academy of Sciences, 96*, 8301–8306.

Gerstadt, C., Hong, Y., & Diamond, A. (1994). The relationship between cognition and action: Performance of children 3½-7 years old on a stroop-like day-night task. *Cognition, 53*, 129–153.

Goschke, T., & Bolte, A. (2014). Emotional modulation of control dilemmas: The role of positive affect, reward, and dopamine in cognitive stability and flexibility. *Neuropsychologia, 62*, 403–423.

Greene, T., & Noice, H. (1988). Influence of positive affect upon creative thinking and problem solving in children. *Psychological Reports, 63*(3), 895–898.

Harnishfeger, K., & Bjorklund, D. (1994). A developmental perspective on individual differences in inhibition. *Learning and Individual Differences, 6*, 331–355.

Hofmann, W., Schmeichel, B., & Baddeley, A. (2012). Executive functions and self-regulation. *Trends in Cognitive Science, 16*, 174–180.

Homack, S., & Riccio, C. (2004). A meta-analysis of the sensitivity and specificity of the stroop color and word test with children. *Archives of Clinical Neuropsychology, 19*, 725–743.

Houwer, J., & Tibboel, H. (2010). Stop what you are not doing: Emotional pictures interfere with the task not to respond. *Psychonomic Bulletin & Review, 17*(5), 699–703.

Ikeda, Y., Okuzumi, H., & Kokubun, M. (2014). Effects of emotional response on the stroop-like task in preschool children and young adults. *Japanese Psychological Research, 56*, 235–242.

Isen, A. (2008). Some ways in which positive affect influences decision making and problem solving. In *, 3. Handbook of emotions* (pp. 548–573).

Jasinska, A., Yasuda, M., Rhodes, R., Wang, C., & Polk, T. (2012). Task difficulty modulates the impact of emotional stimuli on neural response in cognitive-control regions. *Frontiers in Psychology, 3*(345).

Kerns, J., Cohen, J., MacDonald, A., Cho, R., Stenger, V., & Carter, C. (2004). Anterior cingulate conflict monitoring and adjustments in control. *Science, 303*, 1023–1026.

Kramer, H., Lagattuta, K., & Sayfan, L. (2015). Why is happy-sad more difficult? Focal emotional information impairs inhibitory control in children and adults. *Emotion, 15*(1), 61–72.

Lagattuta, K., & Kramer, H. (2017). Try to look on the bright side: Children and adults can (sometimes) override their tendency to prioritize negative faces. *Journal of Experimental Psychology: General, 146*(1), 89–101.

Lagattuta, K., Sayfan, L., & Monsour, M. (2011). A new measure for assessing executive function across a wide age range: Children and adults find happy-sad more difficult than day-night. *Developmental Science, 14*, 481–489.

Langner, R., Leiberg, S., Hoffstaedter, F., & Eickhoff, S. (2018). Towards a human self-regulation system: Common and distinct neural signatures of emotional and behavioural control. *Neuroscience & Biobehavioral Reviews, 90*, 400–410.

McRae, K., Misra, S., Prasad, A., Pereira, S., & Gross, J. (2012). Bottom-up and top-down emotion generation: Implications for emotion regulation. *Social Cognitive and Affective Neuroscience, 7*(3), 253–262.

Montgomery, D., & Koeltzow, T. (2010). A review of the day-night task: The stroop paradigm and interference control in young children. *Developmental Review, 30*, 308–330.

Mueller, S. (2011). The influence of emotion on cognitive control: Relevance for development and adolescent psychopathology. *Frontiers in Psychology, 2*(327).

Munakata, Y., Snyder, H., & Chatham, C. (2012). Developing cognitive control three key transitions. *Current Directions in Psychological Science, 21*(2), 71–77.

Nakagawa, M., Matsui, M., Katagiri, M., & Hoshino, T. (2015). Near infrared spectroscopic study of brain activity during cognitive conflicts on facial expressions. *Research in Psychology and Behavioral Sciences, 2*, 32–38.

Norman, D., & Shallice, T. (1986). Attention to action. In R. Davidson, G. Schwartz, & D. Shapiro (Eds.), *Consciousness and self-regulation* (pp. 1–18). Boston, MA: Springer.

Notebaert, W., Gevers, W., Verbruggen, F., & Liefooghe, B. (2006). Top-down and bottom-up sequential modulations of congruency effects. *Psychonomic Bulletin & Review, 13*, 112–117.

Öhman, A., Flykt, A., & Esteves, F. (2001). Emotion drives attention: Detecting the snake in the grass. *Journal of Experimental Psychology: General, 130*(3), 466.

Öhman, A., & Mineka, S. (2001). Fears, phobias, and preparedness: Toward an evolved module of fear and fear learning. *Psychological Review, 108*, 483–522.

Padmala, S., Bauer, A., & Pessoa, L. (2011). Negative emotion impairs conflict-driven executive control. *Frontiers in Psychology, 2*(192).

Papazacharias, A., Taurisano, P., Fazio, L., Gelao, B., Di Giorgio, A., Lo Bianco, L., Quarto, T., Mancini, M., Porcelli, A., Romano, R., Caforio, G., Todarello, O., Popolizio, T., Blasi, G., & Bertolino, A. (2015). Aversive emotional interference impacts behavior and pre-fronto-striatal activity during increasing attentional control. *Frontiers in Behavioral Neuroscience, 9*(97).

Pereira, M. G., de Oliveira, L., Erthal, F. S., Joffily, M., Mocaiber, I. F., Volchan, E., & Pessoa, L. (2010). Emotion affects action: Midcingulate cortex as a pivotal node of interaction between negative emotion and motor signals. *Cognitive, Affective, & Behavioral Neuroscience, 10*(1), 94–106.

Pessoa, L. (2009). How do emotion and motivation direct executive control? *Trends in Cognitive Sciences, 13*(4), 160–166.

Pessoa, L. (2013). *The cognitive-emotional brain: From interactions to integration*. MIT press.

Pessoa, L. (2017). Cognitive control and emotion processing. In T. Egner (Ed.), *The Wiley handbook of cognitive control*. Wiley-Blackwell: Malden, MA.

Pessoa, L., & Ungerleider, L. G. (2004). Neuroimaging studies of attention and the processing of emotion-laden stimuli. *Progress in Brain Research, 144*, 171–182.

Qu, L., & Zelazo, P. (2007). The facilitative effect of positive stimuli on 3-year-olds' flexible rule use. *Cognitive Development, 22*, 456–473.

R Core Team. (2015). *R: A language and environment for statistical computing*. Vienna, Austria: R Core Team.

Rothbart, M., & Rueda, M. (2005). The development of effortful control. In U. Mayr, E. Awh, & S. Keele (Eds.), *Developing individuality in the human brain: A tribute to*

Michael I. Posner (pp. 167–188). Washington, DC: American Psychological Association.
Rowe, G., Hirsh, J., & Anderson, A. (2007). Positive affect increases the breadth of attentional selection. *Proceedings of the National Academy of Sciences, 104*(1), 383–388.
Russ, S., & Schafer, E. (2006). Affect in fantasy play, emotion in memories, and divergent thinking. *Creativity Research Journal, 18*(3), 347–354.
Schmeichel, B., & Tang, D. (2015). Individual differences in executive functioning and their relationship to emotional processes and responses. *Current Directions in Psychological Science, 24*, 93–98.
Schnall, S., Jaswal, V., & Rowe, C. (2008). A hidden cost of happiness in children. *Developmental Science, 11*(5), F25–F30.
Simpson, A., & Riggs, K. (2005a). Factors responsible for performance on the day-night task: Response set or semantics? *Developmental Science, 8*, 360–371.
Simpson, A., & Riggs, K. (2005b). Inhibitory and working memory demands of the day-night task in children. *British Journal of Developmental Psychology, 23*, 471–486.
Song, S., Zilverstand, A., Song, H., d'Oleire Uquillas, F., Wang, Y., Xie, C., Cheng, L., & Zou, Z. (2017). The influence of emotional interference on cognitive control: A meta-analysis of neuroimaging studies using the emotional stroop task. *Nature Scientific Reports, 7*(2088).
Spencer-Smith, M., & Anderson, V. (2009). Healthy and abnormal development of the prefrontal cortex. *Developmental Neurorehabilitation, 12*, 279–297.
van Steenbergen, H., Band, G., & Hommel, B. (2010). In the mood for adaptation: How affect regulates conflict-driven control. *Psychological Science, 21*(11), 1629–1634.
van Steenbergen, H., Band, G., & Hommel, B. (2011). Threat but not arousal narrows attention: Evidence from pupil dilation and saccade control. *Frontiers in Psychology, 2* (281).
Stifter, C., Augustine, M., & Dollar, J. (2020). The role of positive emotions in child development: A developmental treatment of the broaden and build theory. *The Journal of Positive Psychology, 15*(1), 89–94.
Teper, R., Segal, Z., & Inzlicht, M. (2013). Inside the mindful mind: How mindfulness enhances emotion regulation through improvements in executive control. *Current Directions in Psychological Science, 22*, 449–454.
Tottenham, N., Hare, T., & Casey, B. (2011). Behavioral assessment of emotion discrimination, emotion regulation, and cognitive control in childhood, adolescence, and adulthood. *Frontiers in Psychology, 2*(39).
Verbruggen, F., & De Houwer, J. (2007). Do emotional stimuli interfere with response inhibition? Evidence from the stop signal paradigm. *Cognition and Emotion, 21*(2), 391–403.
Vuilleumier, P. (2005). How brains beware: Neural mechanisms of emotional attention. *Trends in Cognitive Sciences, 9*(12), 585–594.
Weiß, R. H., & Osterland, J. (2013). *CFT 1-R grundintelligenztest skala 1 – revision*. Hogrefe.
Wright, I., Waterman, M., Prescott, H., & Murdoch-Eaton, D. (2003). A new Stroop-like measure of inhibitory function development: Typical developmental trends. *Journal of Child Psychology and Psychiatry, 44*, 561–575.