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Executive Control and the Experience of Regret.

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Abstract

The experience of regret rests on a counterfactual analysis of events. Previous research indicates that regret emerges around 6 years of age (Weisberg & Beck, 2010), marginally later than the age at which children begin to answer counterfactual questions correctly. We hypothesized that the late emergence of regret relative to early counterfactual thinking is a result of the executive demands of simultaneously holding in mind and comparing dual representations of reality (counterfactual and actual). To test this hypothesis we administered two regret tasks along with four tests of executive function (two working memory tasks, a switch task and an inhibition task) to a sample of 104 four-to-seven-year-olds. Results indicated that switching, but not working memory or inhibition, was a significant predictor of whether or not children experienced regret. This finding corroborates and extends previous research that shows that the development of counterfactual thinking in children is related to their developing executive competence (Beck, Riggs, & Gorniak, 2009).

Keywords: Regret; Counterfactual thinking; Executive function; Attentional switching; Complex emotions.

Executive Control and the Development of Regret

One of the distinguishing features of human cognition is the ability to consider alternatives to the here and now. Thoughts about what might have been are counterfactual thoughts and when such thoughts concern better alternatives to the present they often lead to negative emotional affect. This experience is what we typically call 'regret' and researchers have posited that regret serves to promote more beneficial future behavior and even happiness (King & Hicks, 2007).

An additional feature of human behavior is the ability to adapt attentional and motor processes flexibly in the pursuit of complex and abstract goals. The monitoring, selection, and coordination of the cognitive processes involved in complex behaviors have been most often studied under the umbrella term 'executive function'.

In this paper we investigate the relationship between the emergence of counterfactual emotions in early childhood and the development of executive function. We begin by presenting an analysis of regret along with a review of its development. We then set out our reasons for believing that individual differences in executive function predict the experience of regret in young children.

The feeling of regret

When we miss a train or forget to do something important, thoughts of how the world might have been often come to mind. These counterfactual thoughts involve reasoning about alternative possible realities (Roese, 1997) and in adults are typically associated with the experience of regret (Zeelenberg & van Dijk, 2005). Two approaches have been taken in the study of the development of regret. The first, pioneered by Guttentag and Ferrell (2004; Ferrell, Guttentag & Gredelin, 2011) assesses children's understanding of the conditions that lead to regret in others. Guttentag and Ferrell presented children with stories concerning two characters who encountered negative events. In one story two boys cycled along one of two paths around a pond. One boy typically took the left path whereas the other typically took the right path. One morning both boys independently decided to take the same path around the pond. They both had a minor accident (hit a tree and fell off their bikes). Children and adults were asked whether one of the boys felt worse about what had happened. Seven-year-olds and adults judged that the boy whose action was atypical felt worse. Five-year-olds by contrast judged that both boys felt equally sad.

A second approach to regret is to examine when children begin to experience regret themselves for events in which they are personally involved. A recent study by Weisberg and Beck (2010) has addressed this issue. Children played a game in which they chose one of two boxes, both of which contained some stickers. Children rated how happy they felt after the contents of the box they chose were revealed (either 2 or 3 stickers) and again after contents of the non-chosen box were revealed (8 stickers). Children from 5 years of age rated themselves less happy once they discovered they could have won more stickers. Weisberg and Beck interpreted this as evidence of regret. Children younger than 5 years of age by contrast tended to judge themselves as no less happy after the alternative box had been opened than before it had been opened (see also O'Connor, McCormack & Feeney, in press; Weisberg & Beck, in press).

Executive function

Although executive function is implicated in a heterogeneous array of everyday tasks such as planning, organization, problem solving etc., evidence from laboratory studies indicates that the executive system consists of three dissociable but related components: updating and monitoring (interpreted by some as working memory), inhibitory control, and shifting/switching (Collette et al., 2005; Diamond, 2006; Fisk & Sharp, 2004; Lehto, 1996; Miyake et al., 2000).

Studies of the developmental trajectory of executive control have found a general and protracted improvement across a range of executive tasks beginning in early infancy and culminating in early adulthood (Crone, Ridderinkhof, Worm, Somsen, & van der Molen, 2004; Davidson, Amso, Anderson, & Diamond, 2006; Simpson & Riggs, 2005). Although there is some disagreement as to how best characterize the early executive system, with some arguing for a single construct in the preschool years (Espy, Wiebe, & Charak, 2008), the weight of evidence suggests that executive function comprises dissociable subcomponents by at least 6 years of age (Beveridge, Jarrold, & Pettit, 2002; Brocki & Bohlin, 2004; Garon, Bryson, & Smith, 2008; Hughes, 1998).

Domain general executive processing has been implicated in a wide array of domain specific behaviors and abilities which undergo development in early childhood, such as theory of mind (Carlson & Moses, 2001), reading and mathematics (Blair & Razza, 2007). However, no research to date has sought to investigate the link between executive control and the experience of regret. Here, we provide the first investigation of the link between executive control and the counterfactual emotion of regret. We hypothesize that individual differences in children's executive functioning (specifically cognitive flexibility and working memory) will be predictive of whether or not they experience regret.

Executive function and the development of counterfactual emotions

Adult like counterfactual thinking requires that individuals hold in mind dual representations of reality, simultaneously representing events as they occurred as well as representing events as they might have occurred (Santamaria, Espino, & Byrne, 2005). Byrne and colleagues claim that working memory constrains the number of models (their terminology) which individuals construct when reasoning about counterfactuals (Santamaria et al, 2005; Thompson & Byrne, 2002). Moreover, Byrne has made the specific developmental claim that adult-like counterfactual reasoning is difficult for young children precisely because they have limited working memory capacity (Byrne, 2007). Thus on this view, there are grounds for thinking that working memory is an important limiting factor on children's ability to experience regret.

In addition to the working memory demands of holding dual representations in mind simultaneously, experiencing regret requires individuals to actively compare counterfactual alternatives with current reality. This seems likely to be a process which requires cognitive flexibility. Individuals must shift attention back and forth between the counterfactual and the actual in an effortful and controlled manner. Therefore, in addition to the limits which working memory places on counterfactual reasoning we suspect that individual differences in children's cognitive flexibility as measured by switch tasks will also predict whether or not children experience regret. We note that around the age children begin to experience regret significant improvements occur in both children's working memory and cognitive flexibility (Alloway, Gathercole & Pickering, 2006; Chevalier, Dauvier, & Blaye, 2009; Davidson et al., 2006).

We already know that earlier related developments in counterfactual thinking correlate with executive functioning. Beck, Riggs, & Gorniak (2009) found that correct responding to counterfactual questions correlated with inhibitory control. This suggests that what young children find difficult about reasoning from false antecedents is inhibiting what they know to be true about the world (see also Beck, Carroll, Brunsden, & Gryg, 2011). Additionally, Guajardo, Parker, and Turley-Ames (2009) found that both working memory and representational flexibility accounted for a significant percentage of the variance in the ability of 3-to-5-year-olds to generate false antecedent events that would have brought about a given counterfactual outcome.

To explore the relationship between executive control and regret we performed an individual differences study comprising measures of executive function and the experience of regret. We employed four tests of executive function that measured the three subcomponents of working memory, inhibitory control and switching. To assess children's first person experience of regret we used an adapted version of the box games from Weisberg and Beck (2010; see also Amsel & Smalley, 2000). We also included a measure of children's understanding of others' regret taken from Guttentag and Ferrell (2004). Finally, we included a counterfactual reasoning task (marble game) adapted from Beck et al. (2006) to make a preliminary examination of its relation to executive function, although, the results will not be reported here in detail. We hypothesized that there would be a relationship between children's experience of regret, as assessed by the boxes task, and their performance on tasks of working memory and switching. Relatedly, we also examined whether children's understanding of others' regret (the stories task) correlated with executive functioning, though this was not the primary aim of the study.

Method

Participants

A total of 116 children (58 female) took part in this study. Ages ranged from 4 years 2 months to 7 years 9 months. All participants were recruited from the same school. Six children failed to complete both experimental batteries due to absenteeism on the second day of testing, a further two children chose to withdraw from the study and four children from the youngest age group tested failed to follow the test instructions on one or more of the executive function tasks. The final sample therefore consisted of 104 children. The 23 youngest children were drawn from a reception class (first formal year of schooling in the UK) and were tested at the beginning of the school year (*M* = 4 year 6 months (4;6), *SD* = 3.0 months). A further group of 28 older reception age children were tested towards the end of the school year (*M* = 5;4, *SD* = 3.8 months). Twenty-eight children from a year 1 class (second formal year of schooling) (*M* = 6;4, *SD* = 3.3 months) and 25 children from a year 2 class (third year of formal schooling) (*M* = 7;3, *SD* = 3.5 months) were also tested. The participants came from a variety of ethnic backgrounds, however, the majority (74%) were Caucasian.

Procedure

Children were tested individually across two sessions. All testing took place in a gymnasium in the school. Everyone completed the executive function tasks in the first session and the regret and counterfactual tasks in the second session. Each session lasted around 20-25 minutes per child. The two sets of tasks were administered to children a minimum of three days apart and no more than 1 week apart.

Executive function tasks

Participants completed four computer-based tasks of executive function. Stimuli were presented on a 17 inch computer screen. On one task (counting recall) participants made verbal responses, whereas on the remaining tasks participants used two custom-built plastic button boxes. These had a surface area of 12 x 14 cm and a depth of 3.5 cm at the back sloping to 2.5 cm at the front. A circular plastic button (2.5 cm diameter) was situated on the upper middle of each box. The executive function tasks were completed in the same order by all participants as is appropriate for individual differences comparisons (see Beck et al., 2009; Carlson & Moses, 2001); 1. counting recall (a working memory task) 2. eyes task (switching) 3. memory span task (working memory) 4. pictures task (inhibition). Children were given task specific instructions before each task as well as practice trials with feedback. Stimulus presentation times on the counting recall task were self-paced, however, for the other three tasks stimuli were presented for a maximum of

2500 ms on test trials with a 500 ms gap between trials. Test trial blocks on these tasks contained 20 trials.

Counting recall

Counting recall is a measure of verbal working memory (Alloway, Gathercole, Willis, & Adams, 2004; Gathercole & Pickering, 2000). Participants saw an array of blue and red dots on screen and were instructed to count the (4 to 7) red dots only. Once counted, the array disappeared and children were asked to recall the tally of red dots. Participants began by recalling the tally from one array of dots. If they correctly recalled the tally on at least four of six test trials, they proceeded to a block of trials on which they counted and recalled two arrays. The number of arrays on each block of six trials increased by one until they were unable to recall the tallies in order. The test terminated when they responded incorrectly to three trials in a test block. Participants who gave correct responses to the first four trials on any given test block proceeded to the next block and were credited with correct responses to the last two trials of that block. There were four practice trials with feedback (two with one array and two with two arrays). The test retest reliability of counting recall is .74 among 5- to 8-year-olds (Alloway et al.).

Pictures task

The pictures task (adapted from Davidson et al., 2006) is a classic spatial Simon task, measuring inhibitory control. Two pictorial stimuli were presented on a computer screen (a monkey and a cat) and were paired with two response buttons positioned in front of the participant. Specifically, participants were instructed to press the left-hand [blue] button whenever the cat appeared and the right-hand [green] button whenever the monkey appeared. To minimize memory demands a picture of each stimulus was placed above the relevant response button. Stimuli were presented in a pseudorandom order on either the left-hand or right-hand side of the computer screen such that for half the trials the correct response was to press the button on the same side as the location of the stimulus (congruent trials) and for the other half of the trials the correct response was to press the button on the opposite side (incongruent trials). On incongruent trials participants had to inhibit the propensity to press the button ipsilateral with the location of the stimulus. The relative cost to accuracy and reaction times of doing so is a measure of inhibitory control.

Memory span task

The memory span task was adapted from Davidson et al.'s (2006) abstract shapes task. As with the pictures task participants were required to press a button in response to visually presented stimuli. However, unlike the pictures task the stimuli were presented in the middle of the screen eliminating any spatial incongruity effects. Furthermore, there were no visual reminders of the correct stimulus – response button pairings during the task. There were three phases to the task. In phase I, two pictures of objects (umbrella and football cf. abstract shapes in Davidson et al.) were paired with the two response buttons. After training on these associations, participants completed a test block of twenty trials. In phase II, two further stimuli were paired with the left and right button responses (telephone and hammer). Participants were trained on the new associations and given a brief reminder of the stimulus button pairings from phase I. A test block of twenty trials with all four stimuli followed. Finally in phase III, two further stimuli (bananas and flower) were introduced. Participants completed the same training procedure as in phase I & II. They undertook a final test block of twenty trials with all six stimuli, three of which had been paired with the left button and three with the right button.

Eyes task

The eyes task was an adaption of Davidson et al.'s (2006) arrow task and although it placed similar spatial inhibitory demands on participants to that of the pictures task it also had set shifting demands. The target stimulus was a face whose direction of eye gaze was either straight downward or downward and across at a 45º angle (see figure 1). The target stimulus appeared either on the left-hand or right-hand side of the screen. Participants were instructed to press the button that the eyes were looking towards. When the eye gaze of the target stimulus was straight down, the correct response was to press the button congruent to the location of the stimulus (congruent trials). However, when the direction of eye gaze was down and across the correct response was to press the button on the opposite side to the location of the stimulus (i.e. an incongruent response).

Correct responding on the eyes task is dictated by two tacit rules; "press the button on the same side" and "press the button on the opposite side". Participants, therefore, have not only to process the relevant features of the stimulus (as in the pictures task) they also have to make reference to the stimulus location and then instantiate the particular rule that is applicable on that trial. Two task sets are established in this task and costs arise when switching from one task set to the other. The use of bivalent stimuli is crucial to the elicitation of switch costs. When univalent stimuli are employed (such as in the pictures task) little or no switch costs are incurred (Spector & Biederman, 1976). Under these circumstances, as Vandierendonck, Liefooghe and Verbruggen (2010) state, "the two task sets can be maintained active at the same time and performance control can be stimulus based" (p.613). Consistent with other set shifting tasks children and adults are slower and less accurate when the rule is switched from the previous trial compared to when the rule remains the same (Davidson et al., 2006). Performance on the rule switch trials therefore, provides an index of task switching.

Dependent measures

The dependent measure on counting recall and the memory span task was the total number of trials participants responded to correctly and the overall percentage correct trials, respectively. In contrast to the memory tasks, participants were instructed to respond as quickly as possible in addition to as accurately as possible in the pictures task and eyes task. To minimize the influence of a speed accuracy trade off on our results we created composite speed accuracy measures for these tasks. We first standardized participants' accuracy and reaction times measures by converting them to z-scores. Positive z-scores represented greater accuracy and faster reaction times. We then summed accuracy and reaction time z-scores to create a composite measure of performance. The greater the value of the composite score the better performance was on those trials. Only children whose accuracy on the pictures and eyes task was above 60% were included in the final analysis (nine children were removed from the final analysis). This ensures that children who simply respond as fast as they can with no concern for accuracy are not weighted similar to children who respond slower but with greater accuracy.

The dependent measure of inhibitory control taken from the pictures task was participants' performance on incongruent trials relative to congruent trials. To do this we subtracted participants' composite speed accuracy z-score on congruent trials from that on incongruent trials. The larger the value the better participants were doing on incongruent trials relative to congruent trials.

The measure of switching derived from the eyes task was different. Switch costs on this task manifest themselves in two different ways, local switch costs and global switch costs. Local switch costs are the difference in performance between switch trials and non-switch trials. Thus the local switch cost is defined by the local context, that is, whether or not the n^{th} trial is different from trial n-1. The global switch cost is the cost to performance of knowing that one sometimes has to switch between trial types. Evidence of global switch costs come from comparing participants' performance on mixed blocks of congruent and incongruent trials (i.e. blocks which have switch and non-switch trials) with performance on blocks containing only congruent or incongruent trials (i.e. blocks with no switch trials). Participants of all ages are slower and less accurate on non-switch trials in a mixed block (e.g. an incongruent trial which follows an incongruent trial) than they are on incongruent trials in a block containing only incongruent trials (Davidson, et al., 2006). Global switch costs have been reported to have a larger effect on young children's performance (58 – 89 months) and undergo greater developmental change in this age range than local switch costs (Dibbets & Jolles, 2006). As we did not conduct single (unmixed) trial blocks of the eyes task we cannot measure global switch costs independently of local switch costs. Instead we used performance on switch trials as our dependent measure in our individual differences analysis. Performance on these trials is affected both by local and global switch costs. However, we also are able to measure local switch costs independently of global switch costs in our regression analysis by entering switch trial and non-switch trial performance as separate factors.

All of the tasks had a fixed pseudorandom trial order. This ensured that all children had as near as possible the same experience. It also ensured that we had the same number of congruent as incongruent trials in both the pictures task and the eyes task and also the same number of rule switch trials and non rule switch trials in the eyes task. The training procedures for the three tasks that used the response buttons (pictures, memory span and eyes) were very similar. Participants were initially introduced to the rules for that particular task and completed four practice trials. If they made correct responses on at least three of the four practice trials, they proceeded to the experimental block. If they made incorrect responses to at least two of the practice trials, they completed another four practice trials. This continued until they had reached the criteria of three correct responses out of four on a practice trial block. Trials on which reaction times were equal to or quicker than 350ms, so called anticipatory responses (Davidson et al., 2006), were not included in our analysis. If after 2500ms participants had not made a response the trial timed out and was scored as incorrect.

Regret tasks

Boxes game

This task was based on a procedure originally developed by Amsel and Smalley (2000) and extended by Weisberg and Beck (2010). Children were presented with two small boxes (one red and one blue). They were told that they could pick one box and keep whatever they find inside. After they made their choice and received their prize, they were shown the contents of the other box. They then rated how happy they felt on a four point smiley face scale ranging from neutral to very happy (see appendix A). All boxes contained identical stickers – a star on a green background. Before completing the test trials children completed a ‘filler’ trial in which they selected one of the boxes and won one sticker without having the contents of the other box revealed to them and without rating how happy they felt on the scale. The filler trial was included to familiarize them with the procedure and to avoid inflated happiness ratings that may have otherwise occurred on the first test trial due to the novelty of winning a sticker. There were four test trials in total. Two were baseline trials in which the content of the unselected box was identical to the content of the selected box. In Baseline 1 both boxes contained 1 sticker and in Baseline 2 both boxes contained 2 stickers. Two trials were ‘regret’ trials in which the selected box contained fewer stickers than the unselected box. In Regret 1 the selected box contained 1 sticker and unselected box contained 4 stickers. In Regret 2 the selected box contained 2 stickers and the unselected box contained 5 stickers. The four test trials followed one of two counterbalanced orders, Regret 1, Baseline 2, Baseline 1, Regret 2 or Baseline 1, Regret 2, Regret 1, Baseline 2. Participants were judged as feeling regret if they rated themselves as less happy on both of the regret trials in comparison to their respective baseline trial or if they rated themselves less happy on at least one of the regret trials in comparison to the relevant baseline trial but did not rate themselves as more happy on the other regret trial relevant to its baseline comparison trial.

Stories task

Two stories were presented to children, both modeled on the stories of Guttentag and Ferrell (2004) (see Appendix B for the story scripts). In both stories two characters took the same course of action which lead to an unfortunate outcome. For one of the characters the course of action was atypical while for the other character it was typical. Children were asked if one character felt worse than the other or if they both felt the same. The target character was the character whose course of action was atypical.

Marble game

The marble game is a test of counterfactual reasoning adapted from the mouse game reported in Beck et al. (2006). The experimenter gave a marble to the participant to roll down a slide that split into two chutes halfway down. At the bottom of each chute there was a small box to collect the marble. Which way the marble rolled was a matter of chance. At the end of each trial children were asked, “Could the marble have gone anywhere else?” and if they responded ‘yes’, were asked to indicate where else the marble could have gone.

BPVS-II

We administered the BPVS-II (Dunn et al., 1997) to assess children’s receptive vocabulary. On each trial participants selected a picture from an array of four options to match a target word. Each test block contained 12 trials. Test blocks gradually increased in difficulty. Participants proceeded until they gave 4 or fewer correct responses in a test block. The dependent measure was the total number of trials answered correctly.

Results

A preliminary analysis revealed only one gender difference among the dependent measures. Females were significantly more accurate than males on the pictures task congruent trials. We did not investigate the influence of gender in any further analyses. The subsequent results are divided into two sections. First, we examined group scores on the executive function measures and the regret tasks. We then examined individual differences in performance on the tasks.

Executive measures

Table 1 presents the mean scores for each age group on counting recall, memory span, pictures congruent and incongruent trials accuracy and reaction times and eyes non-switch and switch trials accuracy and reaction times.

Pictures task accuracy: A two-way (2 x 4) mixed ANOVA (Analysis of Variance) was performed to examine the effect of congruency across the four different age groups. There was a significant main effect of congruency, $F(1, 100) = 35.71$, $p < .001$, $\eta_p^2 = .26$. Overall participants were less accurate on the incongruent trials (88.8%) than the congruent trials (94.6%). There were no further significant effects or interactions.

Pictures task RTs: A two-way (2 x 4) mixed ANOVA was performed to examine the effect of congruency across age groups. There was a main effect of congruency, $F(1, 100) = 71.91$, $p < .001$, $\eta_p^2 = .42$, a main effect of age group, $F(3, 100) = 26.2$, $p < .001$, $\eta_p^2 = .44$, and an interaction between the two, $F(3, 100) = 3.3$, $p < .05$, $\eta_p^2 = .09$. Follow-up paired sample t-tests revealed an effect of congruency at each age group at the $p = 0.05$ level. Two follow-up one-way between subjects ANOVAs were conducted to compare the effect of age group on reaction time on both congruent and incongruent trials. There was a significant main effect of age group on reaction time on congruent trials, $F(3, 100) = 22.78$, $p < .001$. Post hoc comparisons using the Tukey HSD test revealed that the mean reaction time of 4-year-olds was greater than that for 5-, 6-, and 7-year-olds. The mean reaction time for 5-year-olds was also significantly greater than that for 7-year-olds. The second ANOVA revealed a significant main effect of age group on reaction time on incongruent trials, $F(3, 100) = 23.56$, $p < .001$. Post hoc comparisons using the Tukey HSD test revealed that the mean reaction time of 4-year-olds was greater than that of 5-, 6-, and 7-year-olds The mean reaction time of 5-year-olds was also significantly greater than that of 7-year-olds.

Eyes task accuracy: A two-way (2 x 4) mixed ANOVA was performed to examine the effect of task switching across the four different age groups. There was a main effect of task switching $F(1, 100) = 16.93$, $p < .001$, $\eta_p^2 = .15$, and a main effect of age group, $F(3, 100) = 3.72$, $p < .05$, $\eta_p^2 = .1$, but no interaction. Post hoc tukey HSD tests (at $p < .05$) were conducted to assess the main effect of age group. The accuracy of 7-year-olds (90.8%) was significantly greater than that of 5-year-olds (79.5%) and 4-year-olds (81.4%).

Eyes task RTs: A two-way (2 x 4) mixed ANOVA examining the effect of task switching across age groups revealed a main effect of task switching, $F(1, 100) = 48.18$, $p < .001$, $\eta_p^2 = .33$, a main effect of age group, $F(3, 100) = 14.58$, $p < .001$, $\eta_p^2 = .3$, and a significant interaction between the two, $F(3, 100) = 3.06$, $p < .05$, $\eta_p^2 = .08$. Follow-up paired sample t-tests revealed a significant cost of switching for 4-year-olds, $t(22) = -2.43$, $p < .05$, $r = .46$; 5-year-olds $t(27) = -4.56$, $p < .05$, $r = .66$; and 6-year-olds $t(27) = -4.91$, $p < .05$, $r = .69$ but not for 7-year-olds $t(24) = -1.88$, $p = .07$. A one-way between subjects ANOVA was conducted to compare the effect of age group on reaction time on the non switch trials. There was a significant main effect of age group on reaction time, $F(3, 100) = 12.12$, $p < .001$. Post hoc comparisons using the Tukey HSD test revealed that the mean reaction time of 4-year-olds was greater than that for 6- and 7-year-olds. A one-way between subjects ANOVA was also conducted to compare the effect of age group on reaction time on switch trials. There was a significant main effect of age group on reaction time, $F(3, 100) = 14.98$, $p < .001$. Post hoc comparisons using the Tukey HSD test revealed that the mean reaction time of 7-year-olds was significantly quicker than that of 4-, 5- and 6-year-olds. The mean reaction time of 6-year-olds was also significantly quicker than that of 4-year-olds. No other comparisons were significant.

Regret measures

Boxes task

An initial analysis revealed no effect of trial order. A 2 (regret vs. baseline) by 2 (winning 1 vs. winning 2 stickers) by 4 (4-year-olds vs. 5-year-olds vs. 6-year-olds vs. 7-year-olds) mixed ANOVA revealed a main effect of condition (regret vs. baseline), $F(1, 103) = 29.32$, $p < .001$, $\eta_p^2 = .23$, a significant condition by age interaction, $F(3, 100) = 6.68$, $p < .001$, $\eta_p^2 = .17$, and a significant three way interaction between condition, winnings and age, $F(3, 309) = 2.94$, $p = .04$, $\eta_p^2 = .08$. Four separate 2 (regret vs. baseline) by 2 (winning 1 vs. winning 2 stickers) repeated measures ANOVAs were conducted. There was a main effect of winnings for 4-year-olds, $F(1, 22) = 4.8$, $p = .04$, $\eta_p^2 = .18$. They rated themselves as happier when winning two stickers versus winning one sticker. There was no main effect of condition or winnings among the 5-year-olds. There was a significant main effect of condition for the 6-year-olds, $F(1, 27) = 28.45$, $p < .001$, $\eta_p^2 = .51$, and also for 7-year-olds, $F(1, 24) = 39.43$, $p < .001$, $\eta_p^2 = .62$. Both 6-year-olds and 7-year-olds rated themselves as less happy on regret trials than on baseline trials. Table 2 shows the percentage of participants in each age group who did and did not show regret (in accordance with the criteria described in the methodology).

Stories task

Table 2 shows the percentage of children at each age group who selected the target character as feeling worse on none, one or both of the stories. For the purposes of looking at individual differences we categorized participants who selected the target character in both stories as understanding regret in others and those who selected the target character in only one or none as not demonstrating an understanding of regret in others. A chi square analysis revealed that the proportion of 7-year-olds who chose the target character as feeling worse in both stories was significantly greater than the proportion of the 4-to-6-year-olds who did so, χ^2 (1, N = 104) = 9.71, $p < .05$.

BPVS-II

The mean standardized scores on the BPVS-II for the whole sample was 104 (population mean = 100). There was no difference in standardized scores between the different age groups, however, a one-way ANOVA with age in years as a between subject factor revealed a significant effect of age on raw scores, $F(3, 100) = 19.12$, $p < .001$, r = .60. There was a significant linear trend, $F(1, 100) = 52.17$, $p < .001$, indicating that as age increased BPVS-II raw scores increased proportionally.

Marble game

The overwhelming majority of children answered the counterfactual questions correctly on the marbles game (89%). We were unable to analyze the contribution of individual differences to performance on this task due to ceiling performance.

Individual Differences

Examination of the executive function data revealed that nine participants (3 four-year-olds, 3 five-year-olds, 2 six-year-olds, and 1 seven-year-old) had accuracy scores of less than 60% on either the eyes task or the pictures task. They were removed from the individual differences analysis[1]. We first examined the partial correlations between the executive measures: working memory (counting recall and memory span), inhibition (pictures task) and both switch and non-switch trials on the eyes task and regret measures

[1] The overall outcome of the analysis does not change when these cases are included.

(boxes games and stories task) controlling for the variance accounted for by age and BPVS (Table 3).

Participants' performance on the two regret measures did not significantly correlate with one another. Among the executive measures counting recall performance did not correlate with memory span. Indeed, there were no significant correlations between memory span or inhibitory control and any of the other executive function or regret measures[2]. There were significant correlations between counting recall and performance on both switch ($r = .3$, $p < .05$) and non-switch trials on the eyes task ($r = .391$, $p < .001$). Finally, performance on switch trials of the eyes task (but not non-switch trials) correlated with the experience of regret on the boxes task ($r = .329$, $p = .001$).

Regression analysis

We conducted a hierarchical mixed binary logistic regression analysis with regret on the boxes task (absence or presence) as the dependent measure and age, BPVS, counting recall, memory span, inhibitory control (pictures task), eyes task non-switch trials and eyes task switch trials as the predictor variables. At block one we entered age and BPVS into the model. The likelihood ratio test confirmed that the model at this stage was a significantly better predictor of the experience of regret than the null model, χ^2 (2) = 19.82, $p < .001$. Furthermore, the Hosmer and Lemeshow test indicated that the model provided a good overall fit for the data at this stage, χ^2 (8) = 3.762, $p = .88$. The Wald chi-square statistics indicated that both age, χ^2 (1) = 3.772, $p = .052$, and BPVS, χ^2 (1) = 4.246, $p < .05$, were significant predictors of the outcome. The odds ratio (e^{β}) for both age (1.046) and BPVS (1.042) indicated that as the value of these variables increased so the likelihood of experiencing regret increased.

[2] Without controlling for age and BPVS Inhibition does not correlate with switch, non-switch or counting recall. All other correlations between executive measures are significant.

At block 2 we entered working memory, memory span, inhibition and eyes task non-switch trials into the model in a forward stepwise method using the likelihood ratio method. None of the variables were retained in the model[3]. In the final block we entered switch trial performance to the model. The likelihood ratio test confirmed that this significantly improved the model, χ^2 (1) = 10.379, $p < .001$. Table 4 shows the final regression model which retained age, BPVS and switch trial performance as predictor variables. Compared to the null model the final model was a significantly better predictor of the experience of regret, χ^2 (3) = 30.199, $p < .001$. The Hosmer and Lemeshow test indicated that the final model provided a good overall fit for the data, χ^2 (8) = 10.765, $p = .215$. Analysis of the individual predictor variables in Table 4 indicates that performance on switch trials was the only significant predictor of the feeling of regret in the final model. The positive regression coefficient β and an odds ratio of greater than 1 indicates that increases in our switching measure (better performance on switch trials relative to ones peers) is associated with increased probability of experiencing regret. None of the other variables significantly predicted the outcome.

Discussion

This aim of this study was to explore the relationship between children's experience of regret and their executive control. The results of both the correlational and regression analyses indicated that executive functioning was a strong predictor of four- to seven-year-olds' experience of regret on a simple decision making game. In particular, children's switching ability, not inhibitory control or working memory, predicted the experience of regret. Furthermore, the relationship between switching and the experience of regret did not appear to be mediated by age or receptive vocabulary. This result

[3] Force entering these variables rather than entering them in a stepwise method produces the same result

supports our hypothesis that the development of switching, though not working memory, is related to the emergence of counterfactual emotions.

Tests of switching typically place demands on both inhibitory control and working memory (Diamond, 2006). The current switch task minimized the memory load placed on participants by the use of stimuli that had a non-arbitrary relationship to the correct response on trials. That is, the particular response that participants had to instantiate on any given trial was signaled by the iconic nature of the stimulus (eye gaze directionality). Both the correlational and regression analysis indicate that working memory is not significantly related to the experience of regret in 4-to-7-year-olds. This strengthens the interpretation that it is cognitive flexibility which is predictive of the outcome rather than the other subcomponents of executive function, working memory and inhibitory control.

We interpret the lack of correlation between working memory and regret cautiously. Examining the cognitive differences between individuals who are and are not competent in a particular domain cannot tell us conclusively whether or not a particular factor is involved in a particular ability, it can merely tell us which, if any, are the limiting factors to the ability being studied. Thus, the experience of regret may indeed require a certain amount of working memory capacity, even if individual differences in working memory are not predictive of the experience of regret in our sample.

Nevertheless, the putative role that working memory plays in counterfactual thinking may have been overstated by ourselves and other researchers. Results of earlier studies are mixed. Although Guajardo et al., (2009) found that working memory and representational flexibility predicted antecedent counterfactual generation in 3-to-5-year-olds over and above age and language abilities, Beck et al. (2009) found no relationship between working memory and responses to conditional counterfactual questions among a sample of 3-to-4-year-olds. Interestingly, work on children’s conditional reasoning suggests that it is the *number* of explicit ‘models’ (to use the terminology of Johnson-Laird & Byrne, 1991) required to give the correct interpretation which is sensitive to individual differences in working memory (Barrouillet & Lecas, 1999). The task of Guajardo and colleagues correlated the number of antecedent counterfactual terms children generated with executive function measures. By contrast, neither the current task nor the counterfactual reasoning task of Beck et al. tap individual differences in the number of counterfactual models children generate. We have argued that the experience of regret requires the generation and simultaneous holding in mind of at least one counterfactual model. Such an analysis of events may not itself exhaust children’s limited working memory capacities.

Our primary measure of switching was a combined reaction time and accuracy measure from the eyes switch trials. Performance on this measure is affected by both local switch costs and global switch costs. One potential concern with this measure is that the correlation we observe between it and regret may not have resulted from a direct facilitation of regret by task switching but rather by the influence of a third common variable, such as individuals’ general speed of processing. Two important pieces of evidence, however, count against this. First, contrary to the predictions of a general speed of processing account there was no significant correlation between overall performance on the pictures task and the experience of regret. As with the eyes task the pictures task was a speeded task. Indeed it had the same temporal parameters as that of the eyes task. Secondly, we conservatively entered task performance on the non-switch trials to the regression analysis before entering task performance on the switch trials. Non-switch trials by themselves failed to significantly improve the regression model, moreover, the partial correlation between non-switch trials and regret was non-significant.

The majority of our 6- and 7-year-olds evidenced experience of regret whereas very few children showed evidence of understanding of regret in others (stories task). Although our fixed order individual differences design should make us cautious about direct comparison between the two measures, performance differs to an extent which is unlikely to have been caused by order effects. The small number of children in the current sample who showed evidence of understanding and recognizing regret in others licenses only the most tentative of interpretations with regard to the lack of correlations with both children's own experience of regret and their executive functioning. The relatively late emergence of the understanding of regret in others in comparison to children's own experience of regret suggests, however, that the cognitive processes that support the latter are not in themselves sufficient for the emergence of the former (See also Beck & Crilly, 2009, for a related argument regarding counterfactual reasoning and the understanding of regret in others). This is perhaps not surprising as understanding others' regret in the stories task places additional demands to those which are involved in experiencing regret oneself. In the stories task one not only compares each character's course of action to a counterfactual, but one also has to acknowledge that the availability of the counterfactual alternative action may vary between the characters as a function of how often they take that action (exceptional actions are more mutable than routine actions, Kahneman & Miller, 1986). Moreover, this in turn will impact on how they feel about the actual course of action they took. It is the first part of the process (the comparison of the counterfactual to the actual) that we contend is dependent on cognitive flexibility and that is necessary for the first person experience of regret.

In conclusion, research examining the relationship between emotion and cognition has predominantly focused on the regulatory role of cognition on emotional experiences. The current study by contrast suggests that cognitive processes are intrinsically involved in complex emotional experiences. The cognitive processes in question are those involved in the control of attention and behavior. We have found strong evidence that a core component of this executive system, switching, is correlated with the emergence of the feeling of regret in early to middle childhood. This data taken in conjunction with previous work suggests that a number of developments in executive function are implicated in the development of counterfactual reasoning (e.g. Beck et al., 2009; Guajardo et al., 2009).

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Appendix A

Four point happiness scale ranging in ascending order from 1. not happy 2. a little happy

3. fairly happy 4. very happy

Appendix B

Pond story

Peter and David both ride their bikes to school each morning. There are two paths that go to school around the pond. The blue path and the red path. Everyday Peter cycles around the blue path while David cycles around the red path. Today both Peter and David decided to take the blue path. Unfortunately, there was a tree which fell across the blue path. Both, Peter and David hit the tree, fell of their bikes, were hurt and were late for school. There was no tree across the red path. Who would be more upset about deciding to cycle along the blue path? Peter, who rides along the blue path everyday? Or David who usually takes the red path to school but today who cycled along the blue path? Or do you think they both feel the same

Swing story

This is Jane and Lucy. Jane and Lucy both like to ride the swings in the play park. There are two play parks the yellow one and the green one. Everyday Jane goes to the yellow park. And everyday Lucy goes to the green park. Today both Jane and Lucy decided to go to the green park. Unfortunately, the swings were broke in the green park. Neither, Jane nor Lucy were able to play on the swings that day. The swings in the yellow park were not broken. Who would be more upset about deciding to go to the green park? Lucy, who goes to the green park everyday? Jane who usually goes to the yellow park but who decided to go to the green park today? Or do you think they both feel the same?

Figure 1. Eyes task stimuli

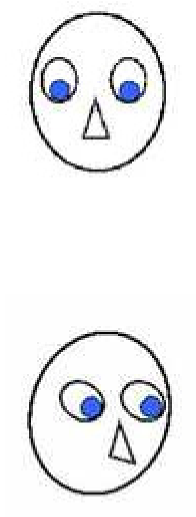

Table 1.

Summary of executive function mean scores by age group

				Accuracy (% of correct trials)				Reaction times (in ms)			
Age group	*N*	Counting recall	Memory span	Pictures		Eyes		Pictures		Eyes	
				Congruent	Incongruent	Non-switch	Switch	Congruent	Incongruent	Non-switch	Switch
4-year-olds	23	7.4	71	91	80	82	80	1230	1447	1367	1455
5-year-olds	28	9	81	96	88	82	77	1014	1153	1237	1372
6-year-olds	28	14.5	84	95	90	89	81	895	985	1064	1229
7-year-olds	25	16	87	96	89	94	88	787	878	947	990

Table 2.

Percentage of children at each age group who selected the target character on none, one or both of the stories; percentage of children who showed evidence of regret on box game

	Story task			Box game
	None	One	Two	Evidence of regret
4-year-olds (*n* = 23)	68	27	5	23
5-year-olds (*n* = 28)	68	18	14	32
6-year-olds (*n* = 28)	71	25	4	68
7-year-olds (*n* = 25)	56	12	32	76

Table 3.

Partial correlations of the executive measures with the counterfactual measures controlling for age and BPVS-II score (N = 95)

	1	*2*	*3*	*4*	*5*	*6*	*7*
1. Regret Boxes	-	-.033	.148	.14	.06	.194	.329**
2. Story regret		-	.176	.016	-.042	-.024	-.071
3. Counting recall	.		-	.16	-.087	.391**	.3*
4. Memory span	.			-	-.194	.192	.199
5. Inhibition					-	-.119	.064
6. Non-switch trials						-	.735**
7. Switch trials							-

* $p < .05$. ** $p < .001$.

Table 4.

Logistic regression analysis for regret in the box game (N = 95)

	B	*SE β*	*Wald's* χ^2	*df*	*p*	e^{β} *(odds ratio)*
Constant	-2.95	1.758	2.817	1	.093	.052
Age	.01	.027	.286	1	.593	1.01
BPVS	.03	.022	1.979	1	.16	1.031
Switch trials	.736	.26	7.985	1	.005	2.087

Note. The analysis was conducted on SPSS version 16.0. Cox & Snell R^2 = .272. Nagelkerke R^2 = .364.