British Journal of Developmental Psychology (2011), 29, 138–147

The British Psychological Society

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Brief report

Developmental differences in the use of task goals in a cued version of the stroop task

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The ability of children ($M = 8.8$ years) and adults ($M = 25.6$ years) to maintain task goals was examined by comparing their performance on a cued version of the Stroop colour-word task. The experimental task presented a cue on each trial that instructed the participant to either read aloud the forthcoming word or name the colour of the word's lettering. Participants were tested with each of two cue-stimulus delays (1,000 and 5,000 ms). Analysis of error rates in the colour-naming condition revealed that children experienced greater interference than adults at each of the cue-stimulus delays. In an effort to separate the relative contributions of colour-naming and word-reading processes, additional analyses were performed based on the process dissociation procedure of Lindsay and Jacoby (1994). While colour-naming process estimates did not vary with age group or cue-stimulus delay, word-reading process estimates were found to vary with age group and cue-stimulus delay. Specifically, adults were superior to children in the inhibition of irrelevant word information only during a long cue-stimulus delay. Collectively, these findings indicate that children have difficulty maintaining task goals in order to suppress stronger, goal-irrelevant responses.

Investigators have recently begun to examine developmental differences in the use of goal information in cognitive control (e.g., Chevalier & Blaye, 2009; Lorsbach & Reimer, 2008, 2010; Marcovitch, Boseovski, & Knapp, 2007; Marcovitch, Boseovski, Knapp, & Kane, 2010; Towse, Lewis, & Knowles, 2007). Contemporary theories of cognitive control emphasize the importance of representing and maintaining goals in working memory (e.g., Braver, Gray, & Burgess, 2007; Braver & West, 2008; Kane, Bleckley, Conway, & Engle 2001; Miller & Cohen, 2001; Munakata, Morton, & O'Reilly, 2007; Oberauer, 2005). For example, Kane *et al.* (2001, p. 180) conceive of 'controlled attention' as a form of executive control that involves the 'ability to effectively maintain stimulus, goal, or context information in an active, easily accessible state in the face of interference, to effectively inhibit goal irrelevant stimuli or responses, or both'. Similarly, Braver and his colleagues (e.g., Braver & West, 2008; Paxton, Barch, Racine,

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DOI:10.1111/j.2044-835X.2010.02011.x

& Braver, 2008) have developed a goal maintenance theory in which cognitive control is regulated through the use of goal information.[1] The central hypothesis of their theory is that cognitive control depends on the ability to represent and actively maintain goal information so that the system may respond appropriately to forthcoming events. Goal representations may be thought of as representations in working memory that determine how other representations are used (Paxton *et al.*, 2008). Specifically, goal representations serve three main functions: (1) an attention function that enhances the processing of less dominant perceptual features or actions, (2) an inhibitory function that suppresses dominant, but goal inappropriate perceptual features or response tendencies, and (3) a maintenance function that keeps goal representations in an active state so that they may continue to guide task-appropriate responses with the passage of time. The purpose of present study was to determine whether there are developmental differences in the ability to actively maintain goal representations in working memory.[2]

The use of goal information is particularly important in tasks that involve strong response competition, such as the Stroop colour-word task (Stroop, 1935). Participants in the Stroop task must actively represent and maintain the goal of providing a weaker, appropriate response (colour naming), while avoiding a stronger, inappropriate response (word reading). The present study used a cued version of the Stroop task to examine whether developmental differences in cognitive control are based, in part, on the ability to actively maintain task goals. Each trial began with the random presentation of one of two task-cues (goals) that instructed the participant to read aloud the forthcoming word (*WORD*) or to name the colour of the word's lettering (*COLOUR*). Randomly varying the task to be performed on each trial places demands on the ability to update task goals and flexibly deploy colour-naming or word-reading processes on a trial-by-trial basis. More importantly, the amount of time between the cue and the stimulus (1,000 or 5,000 ms) was varied in order to examine whether developmental differences exist in the ability to actively maintain updated goal information in working memory.

Assuming that goal representations are graded and that it takes some period of time for those representations to reach full strength (Braver *et al.*, 2001; Braver, Cohen, & Barch, 2002; Munakata, 2001; Perlstein, Larson, Dotson, & Kelly, 2006), if goals are being actively maintained, one would expect performance to improve when more time is provided between the cue and the stimulus. This expectation is also based on the results of previous studies that have examined the performance of healthy young adults on short and long cue-stimulus intervals (1,000 or 5,000 ms) in the cued version of the Stroop (Perlstein *et al.*, 2006; Seignourel *et al.*, 2005). Specifically, younger adult controls in each study showed improved accuracy on the incongruent colour-naming task between the short and the long delay, whereas patients with traumatic brain injury showed no significant change. The strengthening of a goal representation that is being actively maintained during the long delay reflects a proactive use of goal information (Braver *et al.*, 2007). With the additional time provided in a long cue-stimulus delay, one may use the goal information to boost attention to the relevant stimulus features and recruit inhibitory processes that suppress irrelevant information.

[1] *This goal maintenance theory has previously been referred to as theory of context processing (e.g., Braver* et al.*, 2001; Braver, Cohen, & Barch, 2002).*

[2] *Although goal-related processes are the focus of this study, it is clear that a number of other processes are also involved in cognitive control.*

Previous research has demonstrated that both colour and word processes operate in the Stroop colour-word task (Jacoby, Lindsay, & Hessels, 2003; Lindsay & Jacoby, 1994), and that each has a separate time course (Lindsay & Jacoby, 1994; Mutter, Naylor, & Patterson, 2005; Spieler, Balota, & Faust, 1996). Unfortunately, traditional analyses of Stroop interference do not specify the relative contributions of word-reading and colour-naming processes (Daniels, Toth, & Jacoby, 2006; Mutter *et al.*, 2005). However, through the use of a process dissociation procedure, Lindsay and Jacoby (1994) demonstrated that one can measure the separate influences of colour-naming (a non-dominant, yet goal-appropriate response) and word-reading (a dominant, but goal-irrelevant response) processes and their respective time course in the Stroop colour-naming task. A process dissociation analysis of the colour-naming task is based on several key assumptions. First, both word and colour processing are assumed to make independent contributions to performance. Second, correct responses on congruent trials are assumed to reflect the use of both word and colour information. Finally, it is assumed that correct responses on incongruent trials may be made only on the basis of colour information.

The current study used a process dissociation analysis in order to measure whether children and adults differ in their ability to maintain goal information in the cued version of the Stroop colour-naming task.[3] As noted above, the strength of the process dissociation analysis lies in its ability to isolate word-reading and colour-naming processes and to measure the separate time course of these processes in the colour-naming task. According to goal maintenance theory (Braver & West, 2008), the active maintenance of goal information in working memory leads to the inhibition of the dominant, yet goal-irrelevant responses. If goal information is represented and maintained appropriately in the colour-naming task, process dissociation estimates of word reading (a dominant, but goal-irrelevant response) should be reduced, while estimates of colour naming (a weak, yet goal relevant response) may be elevated. If children possess a deficit in the ability to represent the task goal of colour naming, they will exhibit greater word estimates, and perhaps lower colour estimates, than adults at *both* the short and long cue-stimulus delay. It is important to note here that a similar pattern would be found, if performance was based solely on general, age-related differences in inhibitory processes (Bjorklund & Harnishfeger, 1995; Harnishfeger, 1995). However, if children possess a deficit in the ability to actively maintain goal representations in working memory, word estimates will not decrease, nor should colour estimates increase, between the short and the long delay. Therefore, although word and colour estimates of children and adults may be comparable at the short delay, adults should have significantly lower word estimates, and perhaps significantly higher colour estimates, at the long delay.

Method

Participants and design

Participants were 22 children ($M = 8.8$ years, $SD = .38$ years) and 29 adults ($M = 25.6$ years, $SD = 7.31$ years). Age (children or adults), Trial Type (congruent, incongruent, or neutral), Task (colour naming or word reading), and Cue-Stimulus Delay (1,000 or 5,000 ms) were manipulated in a mixed design, with Trial Type, Task, and Cue-Stimulus Delay being varied within participants.

[3] *For extended discussions of issues involving the process dissociation method and its application to the Stroop task see Hillstrom and Logan (1997), Jacoby* et al. *(2003), Jacoby, McElree, and Trainham (1999), and Trainham, Lindsay, and Jacoby (1997).*

Apparatus and procedure

Each participant performed a colour-naming task and a word-reading task, with each being varied on a trial-by-trial basis. Within each task, three trial-types were presented: (1) Congruent – words printed in a colour that matches the word (e.g., GREEN printed in green), (2) Incongruent – words printed in a colour that does not match the word (e.g., GREEN printed in red), and (3) Neutral – five coloured Xs (XXXXX) for the colour-naming trials and colour words (RED, GREEN, or BLUE displayed in white lettering) for word-reading trials. The two tasks and their respective trial types were presented equally often and in a random manner within each of two 72-item trial-blocks, with each block consisting of either a 1,000 or a 5,000 ms cue-stimulus delay. The order in which the two blocks were presented was counterbalanced across participants within each age group. Thus, a total of 144 trials were presented to each participant in two blocks of 72 trials, with trials being equally distributed across task, trial type, and cue-stimulus delay, resulting in 12 trials in each of the conditions.

Each trial consisted of the following sequence: a fixation point (+ sign) (500 ms), a blank screen (500 ms), an instructional cue ('WORD' or 'COLOUR') (750 ms), a blank screen (1,000 or 5,000 ms), and the stimulus event ('RED', 'GREEN', 'BLUE', or 'XXXXX') that remained visible until the participant responded. The stimulus for each trial was removed by the participant's vocal response and was followed by a blank screen (1,500 ms) that represented an inter-trial interval. Stimuli were presented in 28-point uppercase Arial font in the centre of a computer monitor containing a black background. E-Prime software (Schneider, Eschman, & Zuccolotto, 2002) was used to present stimuli and record response accuracy and latency on a Dell laptop computer. Reaction times (RTs) were determined by a voice-activated relay connected to the computer, and the examiner manually coded each response.

Results

Table 1 provides the mean error rates and RTs for the Stroop colour-naming task. Because it requires the use of goal information to overcome a prepotent tendency to read a word, only data from the colour-naming task were analysed. Furthermore, given that the primary

Table 1. Mean arcsine-transformed error rates (% E), correct response times (RT; in ms), and z-scores for children and adults by trial type and cue-stimulus delay in the colour naming task

	Children			Adults		
	Congruent	Incongruent	Neutral	Congruent	Incongruent	Neutral
Cue-stimulus delay						
1,000 ms						
% E	.01 (.03)	.41 (.25)	.03 (.09)	.00 (.00)	.15 (.18)	.02 (.03)
RT	812 (203)	1,149 (285)	919 (180)	725 (156)	946 (252)	705 (156)
z-score	−.52 (.28)	.60 (.69)	−.12 (.23)	−.46 (.21)	.39 (.58)	−.46 (.27)
5,000 ms						
% E	.01 (.03)	.35 (.31)	.04 (.07)	.00 (.00)	.15 (.23)	.01 (.03)
RT	886 (201)	1,245 (337)	974 (147)	856 (188)	1,057 (252)	793 (153)
z-score	−.21 (.33)	.86 (.52)	.15 (.38)	.06 (.40)	.84 (.51)	−.14 (.30)

Note. Standard deviations are in parentheses.

purpose of this research was to focus on the role of goal updating in cognitive control, the analysis focused on interference, but not facilitation, effects in Stroop performance. Unless otherwise indicated, an alpha level of .05 was adopted.

Error rates

Arcsine-transformed error rates were submitted to a 2 (Age: children vs. adult) × 2 (Trial Type: incongruent vs. neutral) × 2 (Cue-Stimulus Delay: 1,000 vs. 5,000 ms) analysis of variance (ANOVA). The effect of Age, $F(1, 49) = 14.842$, $MSE = .054$, and Trial Type, $F(1, 49) = 70.195$, $MSE = 2.978$, were each significant, as was their interaction, $F(1, 49) = 12.703$, $MSE = .539$. The Age × Trial Type interaction was examined through the use of *t*-tests that revealed that children ($M = .382$) displayed significantly higher error rates than adults ($M = .152$) on incongruent trials, $t(49) = 3.775$, but not with neutral trials ($Ms = .034$ and.012, respectively).

Response times

The analysis of RTs included only those trials with correct responses and RTs <200 or >3,000 ms to remove voice key errors. In order to correct for developmental differences in the speed of processing, the analysis of RTs was based on *z*-score transformations.

The effect of age on interference in colour naming was examined by comparing *z*-scores in a 2 (Age: children vs. adults) × 2 (Trial Type: incongruent vs. neutral) × 2 (Cue-Stimulus Delay: 1,000 vs. 5,000 ms) ANOVA. The effect of Age, $F(1, 49) = 8.157$, $MSE = .287$, was significant with children ($M = .373$) producing larger *z*-scores than adults ($M = .\ 157$). The effect of Trial Type was significant, $F(1, 49) = 156.672$, $MSE = 33.417$, with incongruent trials producing larger *z*-scores ($M = .673$) than neutral trials ($M = -.144$). Finally, the effect of Cue-Stimulus Delay, $F(1, 49) = 29.195$, $MSE = 5.275$, was significant, with the 5,000 ms delay producing larger *z*-scores ($M = .427$) than the 1,000 ms delay ($M = .102$).

Process dissociation analyses

Following the method developed by Lindsay and Jacoby (1994), the estimated contributions of word-reading and colour-naming processes were obtained at different *post-hoc* deadlines on the Stroop colour-naming task. Rather than using response latencies as *post-hoc* deadlines, Spieler *et al.* (1996) recommends the use of *z*-scores when comparing groups of participants that vary in speed and variance of response. The use of *z*-scores allows one to compare the relative contributions of word reading and colour naming at approximately equal points in processing between groups of participants (Mutter *et al.*, 2005; Spieler *et al.*, 1996). In the present study, *post-hoc* deadlines were set at −1.0, −0.5, 0.0, 0.5, and 1.0 standard deviations from each participant's mean colour-naming latency (cf. Mutter *et al.*, 2005). The proportion of correct responses by each *z*-score deadline was obtained for congruent and incongruent trials for each participant. Using these proportions, estimates of word reading and colour naming were obtained for each participant at each deadline by solving the following equations: $p(\text{Correct} \mid \text{Congruent}) = \text{Word} + \text{Colour}(1 - \text{Word})$ and $p(\text{Correct} \mid \text{Incongruent}) = \text{Colour}(1 - \text{Word})$. The word contribution is estimated by the following: $\text{Word} = p(\text{Correct} \mid \text{Congruent}) - p(\text{Correct} \mid \text{Incongruent})$. The colour estimate is obtained with the following equation: $\text{Colour} = p(\text{Correct} \mid \text{Incongruent})/1 - \text{Word}$.

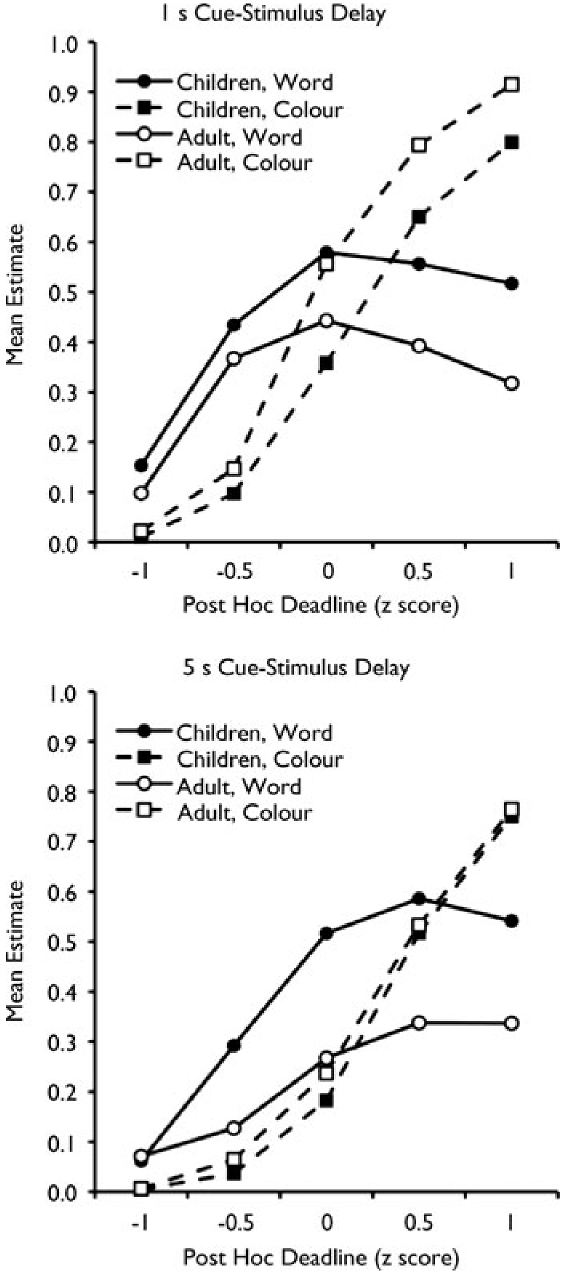

Figure 1. Word and colour process estimates according to age and cue-stimulus delay (1,000 ms in the upper panel and 5,000 ms in the lower panel) at each of five *post-hoc* z-score deadlines.

Estimates for word and colour processes are displayed in Figure 1. Given that the data for the *post-hoc* deadlines are not independent (Mutter *et al.*, 2005), a series of independent sample *t*-tests were used to compare children and adults on the word-reading and colour-naming estimates at each of the three *z*-score deadlines (−0.5, 0.0, and 0.5) within each cue-stimulus delay. Given the number of comparisons required in this analysis, an alpha level of .01 was used in order to protect against Type 1 error rate inflation.

With regard to word-reading processes, children displayed significantly larger word estimates than adults at the −0.5, $t(49) = 3.145$, 0.0, $t(49) = 3.51$, and 0.5, $t(49) = 3.31$ *z*-score deadlines at the 5,000 ms cue-stimulus delay. In addition, the effect of cue-stimulus delay was examined separately within each age group. Although cue-stimulus delay did not impact the performance of children, it had a significant effect on adults, $F(1, 28) = 7.955$, $MSe = .084$, with lower word estimates appearing in the 5,000 ms delay ($M = .228$) than the 1,000 ms delay ($M = .324$). With respect to colour estimates, there was no effect of Age at either Cue-Stimulus Delay for any of the *z*-score deadlines.

Discussion

Consistent with the results of multiple studies (e.g., Bub, Masson, & LaLonde, 2006; Fagot, Dirk, Ghisletta, & de Ribaupierre, 2009), children exhibited greater Stroop interference effects than adults. The process dissociation analysis revealed that word processes were dominant early in the course of processing, and that word processes later gave way to colour processes (cf. Mutter *et al.*, 2005; Spieler *et al.*, 1996). After adjusting the process dissociation estimates of children and adults so that they reflected comparable points in processing, colour estimates for children and adults were found to be equivalent at both the short and the long cue-stimulus delays. This suggests that children and adults were similar in their ability to boost the activation of colour information at both the short and the long cue-stimulus delays.

Despite the absence of age differences in the time course of colour-process estimates, there were age differences in word-process estimates. Recall that elevated estimates of word-reading processes in the colour-naming task reflect an inability to overcome the impulse to provide the dominant, but goal-irrelevant, word-reading response. Although age differences in word estimates were absent at the short delay, word estimates were significantly larger for children than adults at the long delay. The emergence of age differences in word estimates at the long delay reflects the nature of goal maintenance, as well as operation of age-related changes in the ability to actively maintain a goal representation over time. Goal representations are presumed to be graded and strengthened over time through their active maintenance in working memory (e.g., Braver *et al.*, 2001; Munakata, 2001). Age differences in word estimates were not manifested at the short delay, because there was insufficient time for active maintenance to fully strengthen the goal representation of colour naming in either age group. However, because of their superior ability to proactively maintain goal representations over time (Braver *et al.*, 2007; Braver & West, 2008; Lorsbach & Reimer, 2008), adults were able to further strengthen the representation of the instructional cue and thereby override the dominant response tendency of word reading more effectively than children. In the process dissociation analysis, this was manifested in lower word estimates with adults than children. The fact that children did not exhibit a reduction in word estimates at the longer delay indicates that they possessed a deficit in the ability to actively maintain the task cue, resulting in the less effective inhibition of word reading processes.

Importantly, through the use of a short and a long cue-stimulus delay, this account can be contrasted with an alternative interpretation; that is., that age-related differences on this cued version of the Stroop task merely reflect a generalized (non-goal related) deficit in the ability to inhibit dominant response tendencies. If age-related problems of colour naming in this task were based solely on developmental differences in inhibitory processes, one would expect children to exhibit greater word process estimates than adults at *both* the short and long cue-stimulus delays. The fact that age differences were found in word process estimates at the long, but not the short cue-stimulus delay, suggests that the age differences were not due to a more generalized inability to inhibit dominant response tendencies. Rather, the pattern of these results suggests that difficulties with maintaining task goal information over time contributed to developmental differences in the ability to override a dominant response tendency.

Acknowledgements

Grant 1 R15 HD052541 from the National Institute of Child Health and Human Development supported this research. The authors thank Tiffany Ackerman for her help with data collection.

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Received 28 May 2010; revised version received 18 October 2010