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## Cognitive Control and Language Across the Life Span

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Running head: REACTIVE CONTROL AND LABELING IN TASK SWITCHING

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Cognitive control and language across the lifespan: does labeling improve reactive control?

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## Abstract

How does cognitive control change with age, and what are the processes underlying these changes? This question has been extensively studied using versions of the task-switching paradigm which allow participants to actively prepare for the upcoming task (Kray, Eber,& Karbach, 2008). Little is known, however, about age-related changes in this ability across the lifespan when there is no opportunity to anticipate task goals. We examined the effect of two kinds of verbal self-instruction—labeling either the task goal or the relevant feature of the stimulus—on two components of cognitive control, goal setting and switching, in children, young adults, and older adults. All participants performed single-task blocks and mixed-task blocks (involving unpredictable switching between two tasks) in silent and labeling conditions. Participants categorized bidimensional stimuli either by picture or by color, depending on their spatial position in a two-cell vertical grid. Response times revealed an inverted U-shape in performance with age. These age differences were more pronounced for goal setting than for switching, thus generalizing results obtained in situations tapping proactive control to this new context forcing reactive control. Further, differential age-related effects of verbalization were also obtained. Verbalizations were detrimental for young adults, beneficial for older adults, and had mixed effects in children. These differences are interpreted in terms of qualitative developmental changes in reactive goal-setting strategies.

*Keywords:* Cognitive control; Task switching; Verbal labeling; Goal setting; Lifespan

Cognitive control and language across the lifespan: does labeling improve reactive control?

The ability to control and monitor thoughts and actions to achieve goals is one of the most remarkable aspects of human cognition (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Carlson, 2005). This adaptive feature of cognition, referred as cognitive control, has been shown to follow an inverted U-shaped function across the lifespan, with improvement throughout childhood and adolescence (Zelazo & Müller, 2011) followed by decline during aging (Fristoe, Salthouse, & Woodard, 1997). Cognitive control is generally conceptualized as operating through three partially separate executive functions: inhibition, cognitive flexibility, and information updating in working memory (Miyake *et al.*, 2000). Goal setting, the ability to represent and maintain task goals in working memory, has been hypothesized to account for their common variance. This hypothesis is not only supported by structural analyses in adults (Friedman *et al.*, 2008; Miyake *et al.*, 2000), but also by studies in children showing that manipulating the cost of goal setting impacts control efficiency (Blaye & Chevalier, 2011; Chevalier & Blaye, 2009).

Goal setting is usually investigated by assessing the ability to anticipate upcoming events (i.e., set the goal ahead of time). However, many situations prevent anticipation of the upcoming task goal (e.g., having to plan a new route at the very last minute because the usual highway exit is unexpectedly closed), thereby constraining the use of reactive control. Little is known about the processes underlying reactive goal setting and their developmental trajectory. To fill in this gap, the present study examined age-related changes in reactive goal setting, by comparing the influence of two forms of verbal self-instructions on goal-setting efficiency in children as well as young and older adults.

One of the most demanding situations, in cognitive control terms, is alternating between tasks. Task alternation requires the selection of the goal that is to be performed next from among different potential goals, and the implementation of a task switch in order to achieve the new goal. In the task-switching paradigm, the role of goal setting has been operationally distinguished from switching per se. In this paradigm, participants are asked to switch back and forth between two tasks. For instance, they may have to categorize bidimensional stimuli by shape and by color (Kiesel et al., 2010; Vandierendonck, Liefvooghe, & Verbruggen, 2010). This paradigm contains single-task blocks in which the task remains the same across all trials, and mixed blocks, which involve both non-switch trials, in which the task is the same as in the previous trial and switch trials, in which the task differs from that of the previous trial. Differences in performance between these two trial types assess switching costs. Goal-setting is measured by mixing costs, consisting in performance differences between trials in single-task blocks and non-switch trials in mixed blocks, as neither requires switching and only the latter requires selecting among two possible goals (Rubin, & Meiran, 2005). Age-related changes have been found in goal setting and switching, with a more pronounced U shape for the former (e.g., Cepeda, Kramer, & Gonzalez de Sather, 2001; Karbach & Kray, 2007; Reimers & Maylor, 2005). This reveals the critical role of goal setting in the development of efficient cognitive control.

Two forms of goal setting can be distinguished based on the “dual mechanisms of control” theory (Braver, Gray, & Burgess, 2007). This theory contrasts two forms of cognitive control which differ in their temporal dynamics. During a cognitive task, proactive control is engaged in advance to anticipate conflict, whereas reactive control is engaged post-conflict to overcome it. Proactive control relies on early activation and active maintenance of the task goal in working memory (e.g., sorting by color) before stimulus onset, to bias attention toward the goal-relevant stimulus information (e.g., orange color) and to ignore distracting

information (e.g., dog shape). Although proactive control makes high demands on working memory, it prevents potential conflict due to the simultaneous presentation of relevant and irrelevant stimulus features. Reactive control, in contrast, is characterized by the transient maintenance of task goals, which are briefly activated after stimulus onset, in reaction to both task-relevant and task-irrelevant stimulus information (e.g., an “orange dog” stimulus activates “orange” and “dog” as potential responses). Hence, the need to resist the interference induced by task-irrelevant information makes the exertion of reactive control especially demanding. Young adults predominantly use proactive control, whereas older adults and young children mostly engage reactive control (Braver, Satpute, Rush, Racine, & Barch, 2005; Chatham, Frank, & Munakata, 2009; Munakata, Snyder, & Chatham, 2012; Paxton, Barch, Storandt, & Braver, 2006).

Although young adults’ greater cognitive control, relative to children and older adults, is thought to result from its proactive characteristic (Kramer, Hahn, & Gopher, 1999; Mayr, 2001), it is not known whether young adults’ advantage holds when goals can only be set reactively. The present study addressed this question by preventing proactive goal setting through the simultaneous display of task cues and stimuli in the task-switching paradigm. Two alternative hypotheses were tested: if young adults’ advantage is exclusively due to a greater ability to exercise proactive control, then age-related differences might be reduced or even disappear in contexts where proactive goal setting is impossible. Alternatively, young adults may excel at any kind of control, and showing greater goal-setting abilities than children and older adults, even when goals have to be set reactively.

Further, we examined whether reactive goal setting can be supported by language. Consistent with the seminal work of Luria (1961) and Vygotsky (1988), a growing body of studies using the task-switching paradigm has shown that language support proactive goal setting (Kray, Eber, & Karbach, 2008; Saeki & Saito, 2004). Specifically, articulatory

suppression, which prevents the use of inner speech, was found to increase mixing costs (Fernyhough & Fradley, 2005; Saeki & Saito, 2004), whereas verbal self-instructions considerably reduced these costs, while not affecting switch costs (Kray, Lucenet & Blaye, 2010; Kray et al., 2008). Verbalizations are thought to support goal setting by providing a medium to translate arbitrary task cues into an explicit representation of task goals (e.g., Arrington, Logan, & Schneider, 2007; Chevalier & Blaye, 2009). Interestingly, children and older adults benefit more from open verbal strategies than younger adults, which is consistent with Vygotsky's proposal that inner speech is not entirely mature and efficient before mid-childhood (see also, Winsler & Naglieri, 2003). Therefore, language seems to play a crucial role in proactive goal setting (Cragg & Nation, 2010).

However, the question of the influence of verbal self instructions on goal setting in contexts where the goal has to be set reactively remains open. This question is of great theoretical interest because reactive goal setting likely involves different cognitive processes than proactive goal setting. In contexts promoting proactive control, verbal labeling is requested before the stimulus onset, which diminishes the interference of the irrelevant stimulus features or even eliminates this conflict before it occurs. In contrast, verbal labeling in reactive context may be used to resolve the conflict induced by the co-occurrence of both relevant and irrelevant features after this conflict occurred.

A related question is whether goal labeling only can support reactive goal setting (e.g., saying "color"), or whether verbalizing other task-relevant information can also enhance goal setting. Indeed, labeling the relevant stimulus feature (e.g., saying "orange") can be critical to enhancing toddlerhood and preschool cognitive control by reinforcing appropriate representations for the current task and reducing the saliency of irrelevant representations (Kirkham, Cruess, & Diamond, 2003; Müller, Zelazo, Hood, Leone, & Rohrer, 2004; Towse, Redbond, Houston-Price, & Cook, 2000). To further address this question, the present study

contrasted the effects of goal- and relevant stimulus-feature labeling on reactive goal setting. Labeling relevant information, be it the goal or the relevant stimulus feature, should help overcome the interference of distracting information, especially in children and older adults, who recruit inner speech less efficiently than do young adults. As labeling the relevant stimulus feature implies making a decision on which dimension is relevant (shape vs. color), it implicitly requires setting one's goal. Hence, it could support goal setting, perhaps even more so than goal labeling, since relevant stimulus-feature labeling provides further assistance in the selection of the final response (orange vs. blue).

In the present study, children as well as younger and older adults were tested using a variant of the task-switching paradigm in which they had to set goals reactively in silence and in a condition requesting to say aloud self-directed instructions.

## Method

### Participants

Forty-seven children (age range = 8-9 years), 48 younger adults (age range = 17-28 years), and 45 older adults (age range = 64-86 years) were randomly assigned to two labeling groups (i.e., goal vs. relevant-feature). Participants in the two labeling groups did not differ in processing speed and working memory, as assessed by Kray et al.'s (2010) task and the backward digit span task (Wechsler, 1981, 2003), respectively (all  $ps > .46$ ). Because verbal abilities and levels of formal education may affect task strategies, the two adult age groups were matched on performance in the Mill-Hill vocabulary test ( $p = .63$ ) (Raven, Court, & Raven, 1986) and on number of years of formal education ( $p = .76$ ). Children were drawn from a school in Marseille and adults from a database of participants at Aix-Marseille University. Informed consents were obtained from adults and children's parents. All participants spoke French as their first language, and had normal or corrected-to-normal

vision. Most participants were Caucasian and came from middle-class backgrounds, although race and socioeconomic status data were not collected. Data for eight participants (two children, two young adults, and four older adults) were discarded from analyses because their error rates were more than three standard deviations above the corresponding age group means. The characteristics of the final sample are summarized in Table 1.

<Insert Table 1 about here>

## Materials

Stimulus presentation and response recording were controlled by a HP Compaq 9000 laptop using E-prime software (Psychology Software Tools, Inc., 2007). Bivalent stimuli consisted of 64 line drawings of four different dogs and four different cars displayed in four different shades of orange and four different shades of blue (i.e., from light to dark).

On each trial, the stimulus was displayed in one of two locations within a two-cell grid (Bryck & Mayr, 2005; Kray et al., 2010). On the picture task, the stimulus always appeared in the upper cell within the grid, and participants had to categorize the picture as a dog or a car. On the color task, stimuli always appeared in the lower cell, and participants categorized their color as orange or blue. Hence, the task cue was the stimulus position on the screen, thereby preventing proactive goal setting ahead of stimulus onset. The responses for both picture and color tasks were mapped onto two buttons (q-key for dog or orange and p-key for car or blue).

## Procedure

The testing session began with a short demographic questionnaire. All participants were tested in two consecutive sessions corresponding to the control condition, where they were asked to remain silent, and the labeling condition. The order of conditions was counterbalanced between participants. The labeling condition differed as a function of

labeling groups: participants in the goal-labeling group had to say the task goal (“picture” or “color”) aloud, whereas the relevant-feature-labeling group verbalized the stimulus feature (“dog” or “car” for the picture task, and “orange” vs. “blue” for the color task). Labels were requested at stimulus onsets. Each condition involved a training phase followed by an experimental phase. Each phase consisted of two sets of four blocks, beginning with two single-task blocks (picture task, then color task) followed by two mixed blocks. In the mixed blocks, the picture and color tasks were alternated pseudo-randomly (i.e., no more than three switch trials in a row). Participants received no feedbacks. Each block consisted of 17 trials, yielding a total of 136 training trials and 136 experimental trials per condition (see Figure 1). Mixed blocks included the same number of non-switch and switch trials. Moreover, both single- and mixed-task blocks included an equal number of the four stimulus types (dogs/orange, dogs/blue, cars/orange, cars/blue).

An instruction screen, indicating the upcoming task(s) to be performed in the following block and whether labeling was required or not, was presented at the beginning of each block. Each trial began with stimulus display and ended with the participant’s response. The response-stimulus interval (RSI) was 1000 ms (see Figure 2).

<Insert Figure 1 and 2 about here>

## Results

Error rates were at floor in each age group (< 5%), and therefore were not further analyzed. Response times (RTs) were measured from stimulus onset to participants’ key press. Analyses of RTs were run on test trials after dropping the first trial of each experimental block, because first trials cannot be classified as either switch or non-switch. Analyses were conducted on correct responses only, after discarding trials following an incorrect response since errors (e.g. performing the color task whereas the picture task was

required) might change the status (switch vs. non-switch) of the following trial. Trials with labeling errors (e.g., naming “dog” instead of “picture” in the goal-labeling group) were also dropped (0.97% of trials deleted in children, 0.68% in younger adults, and 0.46% in older adults), as well as outliers (i.e., trials with latencies faster than 200 ms and/or beyond two standard deviations from the participant’s mean RT (0% of trials deleted in children, 0.02% in younger adults, and 0.01% in older adults).

In the following section, we first report age-related differences in the control condition, in order to give a picture of the development of cognitive control when only reactive control is possible. Then, we report the effects of the different types of labeling. These effects remained reliable on the basis of proportional scores.

#### Development of Goal Setting and Switching Implementation

An ANOVA was run on performance in the control condition with age group (children, younger adults, older adults), labeling group (goal, relevant-feature) and order of conditions (control first, labeling first) as between-subjects factors and trial type (single, non-switch, switch) as a within-subject factor. The analysis revealed a linear age effect,  $F(2, 120) = 55.38, p < .001, \eta^2p = .48$ , and a quadratic age effect,  $F(2, 120) = 110.73, p < .001, \eta^2p = .47$ , indicating that young adults responded faster ( $M = 674$  ms) than children ( $M = 1044$  ms) and older adults ( $M = 1065$  ms), who did not differ ( $p = .62$ ). A significant effect of trial type,  $F(2, 252) = 435.44, p < .001, \eta^2p = .77$ , revealed significant switching and mixing costs, that is, longer latencies on switch trials ( $M = 1121$  ms) compared to non-switch trials ( $M = 1006$  ms),  $F(1, 120) = 439.74, p < .001, \eta^2p = .78$ , and longer latencies on non-switch trials compared to single trials ( $M = 655$  ms),  $F(1, 120) = 110.63, p < .001, \eta^2p = .47$ , respectively. A significant interaction between order of conditions and trial type,  $F(2, 240) = 3.41, p < .05, \eta^2p = .02$ , was observed. Switching costs did not differ between control-first and labeling-first

orders ( $M = 113$  ms vs.  $M = 117$  ms,  $p = .82$ ), whereas mixing costs were significantly smaller in the label-first condition ( $M = 389$  ms vs.  $M = 313$  ms),  $F(1, 120) = 5.25$ ,  $p < .05$ ,  $\eta^2p = .04$ .

Finally, the Age Group  $\times$  Trial Type interaction was also significant,  $F(4, 240) = 13.97$ ,  $p < .001$ ,  $\eta^2p = .18$ . A quadratic age trend was found for mixing costs,  $F(1, 120) = 26.68$ ,  $p < .001$ ,  $\eta^2p = .18$ , and for switching costs,  $F(1, 120) = 5.32$ ,  $p < .05$ ,  $\eta^2p = .04$ . As shown in Figure 3, young adults demonstrated lower switching costs ( $M = 80$  ms) than children ( $M = 133$  ms),  $F(1, 120) = 4.05$ ,  $p < .05$ ,  $\eta^2p = .03$ , and older adults ( $M = 133$  ms),  $F(1, 120) = 3.85$ ,  $p < .06$ ,  $\eta^2p = .03$ , who did not differ significantly ( $p = .99$ ). Mixing costs were significantly larger for older ( $M = 455$  ms) than for younger adults ( $M = 230$  ms),  $F(1, 120) = 29.72$ ,  $p < .001$ ,  $\eta^2p = .19$ , and children ( $M = 367$  ms),  $F(1, 120) = 4.43$ ,  $p < .05$ ,  $\eta^2p = .03$ . Children also showed substantially greater mixing costs than younger adults,  $F(1, 120) = 11.66$ ,  $p < .001$ ,  $\eta^2p = .08$ .

<Insert Figure 3 about here>

### Labeling Effects on Goal Setting and Switching Implementation

A mixed-groups analysis of variance was run on latencies in the experimental task conditions with age group (children, younger adults, older adults), labeling group (goal, relevant-feature) and order of conditions (control first, labeling first) as between-subjects factors and trial type (single, non-switch, switch) and task condition (control, labeling) as within-subject factors. A significant linear main effect of age was obtained,  $F(2, 120) = 13.47$ ,  $p < .001$ ,  $\eta^2p = .18$ , as well as a significant quadratic age effect,  $F(2, 120) = 15.36$ ,  $p < .001$ ,  $\eta^2p = .18$ . Older adults ( $M = 1151$  ms) and children ( $M = 654$  ms) were slower than younger adults ( $M = 1018$  ms). There were no significant effects of labeling group or order of conditions ( $p = .25$  and  $p = .40$ , respectively) and these two variables did not interact with

other variables of interest (all  $ps > .06$ ). Trial-type effect was significant,  $F(2, 240) = 760.18$ ,  $p < .001$ ,  $\eta^2p = .86$ , showing significant switching ( $M = 133$  ms) and mixing costs ( $M = 364$  ms),  $F(1, 120) = 281.94$ ,  $p < .001$ ,  $\eta^2p = .70$ , and  $F(1, 120) = 747.05$ ,  $p < .001$ ,  $\eta^2p = .86$ , respectively.

Although no main effect of task condition was found ( $p = .32$ ), the interaction between age group and task condition,  $F(2, 120) = 45.45$ ,  $p < .001$ ,  $\eta^2p = .43$ , and the Trial type  $\times$  Task condition  $\times$  Age group,  $F(4, 240) = 18.91$ ,  $p < .001$ ,  $\eta^2p = .23$ , were significant. To explore these interactions, the effects of labeling (collapsing the goal and stimulus-feature labeling conditions) on switching and mixing costs were tested separately within each age group (see Figure 4). Neither costs were significantly modified by labeling in children (switching cost,  $M = 161$  ms,  $p = .36$ ; mixing costs,  $M = 422$  ms,  $p = .12$ ). Younger adults experienced larger switching and mixing costs in the labeling condition ( $M = 190$  ms and  $M = 402$  ms) than in the control condition ( $M = 80$  ms and  $M = 230$  ms); switching costs,  $F(1, 126) = 14.14$ ,  $p < .001$ ,  $\eta^2p = .10$ , mixing costs,  $F(1, 126) = 25.56$ ,  $p < .001$ ,  $\eta^2p = .16$ . In contrast, older adults benefited from labeling, with a significant decrease in mixing costs when using labels ( $M = 306$  ms) as compared to the control condition ( $M = 455$  ms),  $F(1, 126) = 3.95$ ,  $p < .05$ ,  $\eta^2p = .03$ . Their switching costs, however, did not differ between task conditions ( $M = 103$  ms vs.  $M = 133$  ms,  $p = .26$ ).

<Insert Figure 4 about here>

To qualify this observation, we looked at individual patterns of mixing costs with and without labeling in each age group. In both adult groups, the number of participants who benefited from labeling<sup>1</sup> differed significantly from the number who were negatively affected ( $p < .02$  for older adults and  $p < .001$  for younger adults), thereby showing that the pattern observed at the group level occurred in a majority of individuals. In contrast, the proportions

of children benefiting from and impeded by labeling did not differ (Chi<sup>2</sup> goodness of fit Test,  $p > .20$ ). Interestingly, the effect of labeling on mixing cost appeared to be correlated with processing speed in children,  $r = -.44$ ,  $p < .001$ , with faster children experiencing a detrimental labeling effect. In other words, the cost of being required to verbalize was greater among children whose processing speed was closer to that of adults.

## Discussion

The present study investigated the development of reactive control in children, younger adults and older adults. More specifically, we examined age-related differences in the effects of two forms of labeling on goal setting. The present results revealed an inverted U-shaped age function for goal setting, showing that reactive goal setting is most efficient early in adulthood, just like proactive goal setting (e.g., Cepeda et al., 2001). A similar inverted U-shaped curve was found for switching, albeit less pronounced than for goal setting, hence revealing that change in goal setting drives the development of reactive control to a greater extent than change in switching per se. Although young adults' more efficient proactive goal setting is generally thought to reflect better use of preparation delays (Kramer et al., 1999; Lawo, Philipp, Schuch, & Koch, 2012; Mayr, 2001), our findings suggest that young adults' advantage is not limited to better use of preparation delays. Young adults are also better at overcoming conflict created by the co-occurrence of relevant and irrelevant stimulus features in a reactive context. This bottom-up reactivation of task goals has previously been related to a transient activation of lateral prefrontal cortex (Braver, 2012). Prefrontal cortex is one of the last brain structures to reach maturity in adolescence (Amso & Casey, 2006; Diamond, 1991), but also one of the first to deteriorate during aging (Haug & Eggers, 1991; Park & Reuter-Lorenz, 2009). This could account for younger adults' superior performance in the reactive context of the current study. Furthermore, analyses of the effects of verbal self-instructions

highlight qualitative differences between children, younger adults, and older adults in the processes underlying reactive control, thereby specifying the regulatory role of language pointed out by Luria (1961) and Vygotsky (1988). Indeed, labeling the goal or the relevant stimulus feature helped older adults to reduce their goal-setting costs. Unexpectedly, requesting younger adults to use verbal labels increased their goal-setting costs. These two labeling patterns were observed in two subgroups of children, differentiated by their speed of processing.

Previous empirical studies testing task-relevant labeling in a proactive context have demonstrated a benefit in young adults (e.g., Kirkham, Breeze, & Mari-Beffa, 2012; Kray et al., 2008; Kray et al., 2010). The only difference between these studies and ours—albeit a major one—was their allowance of preparation time before each stimulus. The contrast of the present findings with Kray et al.'s (2010) is particularly striking, since these authors used the same stimuli, arbitrary spatial cues, and tasks. It suggests that young adults adopted different strategies in the two studies. The preparation time provided in Kray et al.'s (2010) study enabled participants to use proactive control by retrieving the task goal between task cue and stimulus onset. In this context, labeling may have supported systematically efficient task preparation in young adults, which has previously been found not to occur (De Jong, 2001). Thanks to labeling, the retrieved goal could then help participants orient their attention toward the relevant stimulus feature, thereby reducing interference from the irrelevant one and hence protecting them against conflict due to the simultaneous display of the two stimulus features. By contrast, in the reactive context of the current study, insofar as the goal can be set only after stimulus onset and thus after the display of both relevant and irrelevant stimulus features, retrieving the name of the task goal no longer prevents conflict, although it can help overcome it. However, an optimal way to reduce the conflict due to irrelevant information could be to solve the task based on cue-stimulus-response associations (e.g., blue dog in upper cell means

left press), instead of processing the stimulus features. Such an associative mode of processing makes a verbal representation of the task goal or the relevant stimulus feature unnecessary and may interfere with task processing as labeling becomes an irrelevant secondary verbal task. The suggestion that younger adults used an associative mode of processing in the present study seems particularly plausible given their fast learning of associations, attributed in particular to their speed of processing (Kail & Salthouse, 1994; Kray & Eppinger, 2006; Kray, Karbach, & Blaye, 2012)<sup>2</sup>.

Some children benefited from labeling, just like older adults, whereas labeling impaired other children's performance. Interestingly, children showing detrimental labeling effects also showed higher processing speeds, which is consistent with the hypothesis that they could have adopted an associative processing mode similar to that of young adults. In contrast, the use of cue-stimulus-associations in populations with lower processing speeds (i.e., older adults and the slower-processing group of children) is somewhat implausible due to their probable difficulties in processing and maintaining all of the arbitrary pieces of information involved in the task (i.e., the meanings of spatial cues and response keys). Hence, these participants have to rely on retrieving the task goal to focus on relevant information and select the correct response. The use of this control strategy is then enhanced by goal- or relevant stimulus feature labeling. Although it cannot prevent conflict, this mode of processing enables resistance to interference from the irrelevant stimulus feature, and thus allows conflict resolution. The contrasted patterns of labeling in the two subgroups of children suggest that there might be a shift in control strategies around ages 8 to 9 (see also Chevalier, Huber, Wiebe, & Espy, 2013). In order to test this hypothesis, future research should investigate the development of these strategies within and around this age range. Here, a longitudinal study with 7- to 10-year-olds could be critical in revealing the time of emergence of adult-type efficient control strategies. Homogeneous beneficial effects of labeling before

the age of 8, and detrimental effects after the age of 9, would provide support for this hypothesis. In children and older adults, the lack of differences between the beneficial effects of the two types of labeling (goal vs. relevant stimulus feature) showed that the critical aspect of labeling is not so much its content, but the fact that it facilitates the retrieval of a representation of the goal. The present findings seem to support our conjecture that together with goal labeling, labeling the relevant stimulus feature could also enhance goal retrieval, since in order to decide what the relevant feature is (e.g., orange), one must first retrieve the current task goal (e.g., color).

A major limitation of the present study is the use of a cross-sectional design that may confound age differences with cohort differences (Schaie, 2005). In particular, cohort differences are often revealed through differences in years of education. However, this variable did not differ between our two adult groups ( $p = .76$ ), which reduces the likelihood of cohort effects, at least in adults. Additional measures such as cultural variation (e.g., environmental influences, patterns of socialization) could also be considered in further studies.

To summarize, age-related changes in proactive control have recently received a great deal of attention. However, the development of cognitive control cannot be reduced to the rise and fall of proactive control with age. Even when the only possible form of control is reactive, young adults still outperform children and older adults, highlighting the critical role of reactive control in the development of cognitive control more generally. Furthermore, changes in reactive control involve qualitative changes in control strategies beyond the timing of their engagement.

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## Footnotes

<sup>1</sup>For each participant, we computed the ratio of the difference between labeling and control mixing costs to the control mixing cost. Ratios under -0.2 or over 0.2 were considered to indicate beneficial and detrimental effects, respectively.

<sup>2</sup>Note that, although our stimuli consisted of four different dogs and four different cars displayed in four shades of blue and four shades of orange, participants may have built up four verbal representations (i.e., blue dog, blue car, orange dog, and orange car) through their inner speech, reducing stimulus variability to only four categories.

Figure captions

*Figure 1:* Procedure common to the two task conditions.

*Figure 2:* Details of experimental procedure.

*Figure 3:* Switching and mixing costs (in ms) as a function of age group (children, younger adults, older adults) in the control condition. Error bars refer to the standard errors of the means.

*Figure 4:* Costs as a function of age group (children, younger adults, older adults) and task condition (control, labeling). Error bars refer to the standard errors of the means.

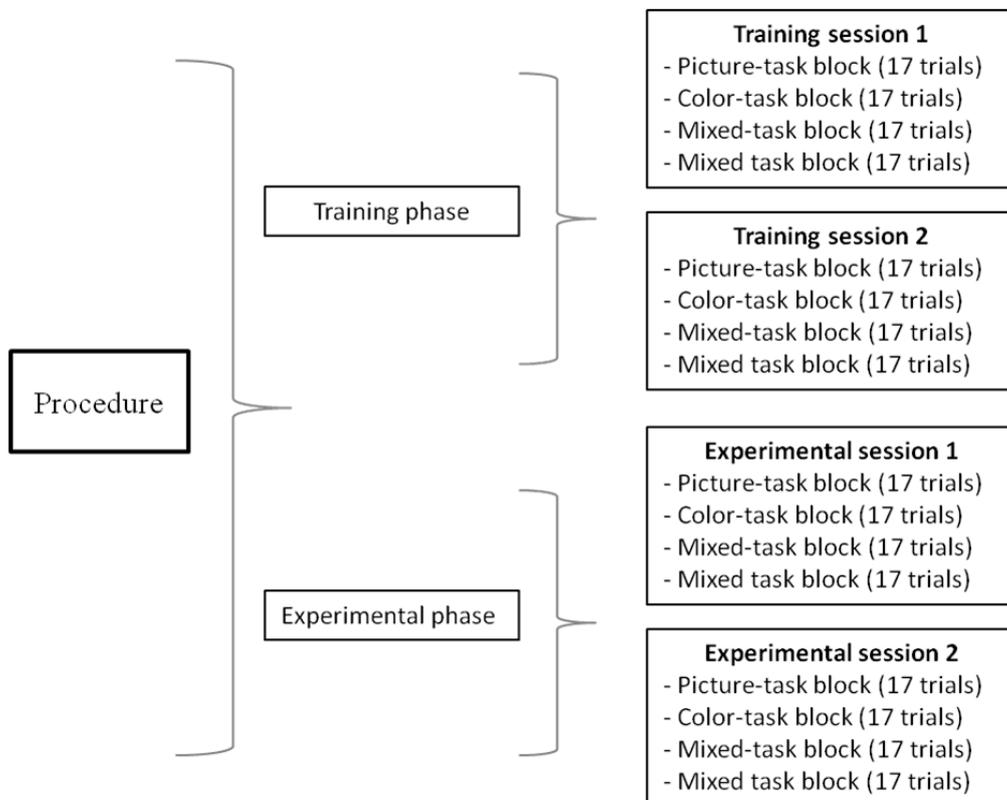


Figure 1.

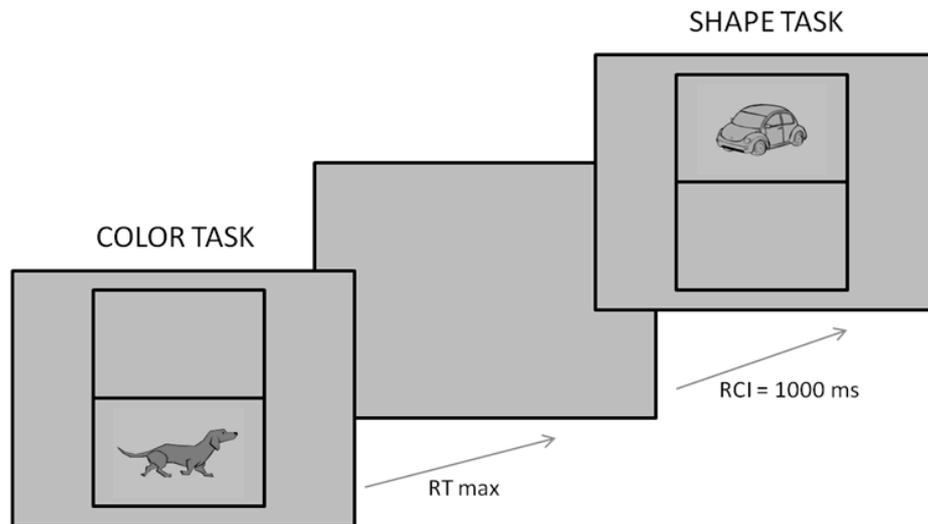


Figure 2. Upon the presentation of the stimulus, participants were required to press the correct response key as quickly and accurately as possible. In the control condition, participants were asked to perform the task in silence. In the goal-labeling group, they were expected to verbalize aloud either the name of the task (i.e., “color” or “picture”), and in the relevant stimulus feature labeling group they were to name the relevant feature of the stimulus, i.e., “orange” or “blue” for the color task and “dog” or “car” for the picture task.

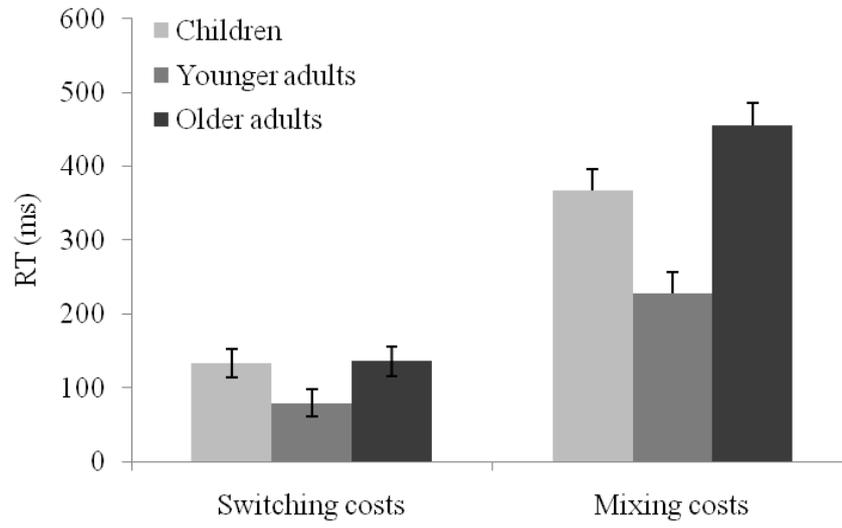


Figure 3.

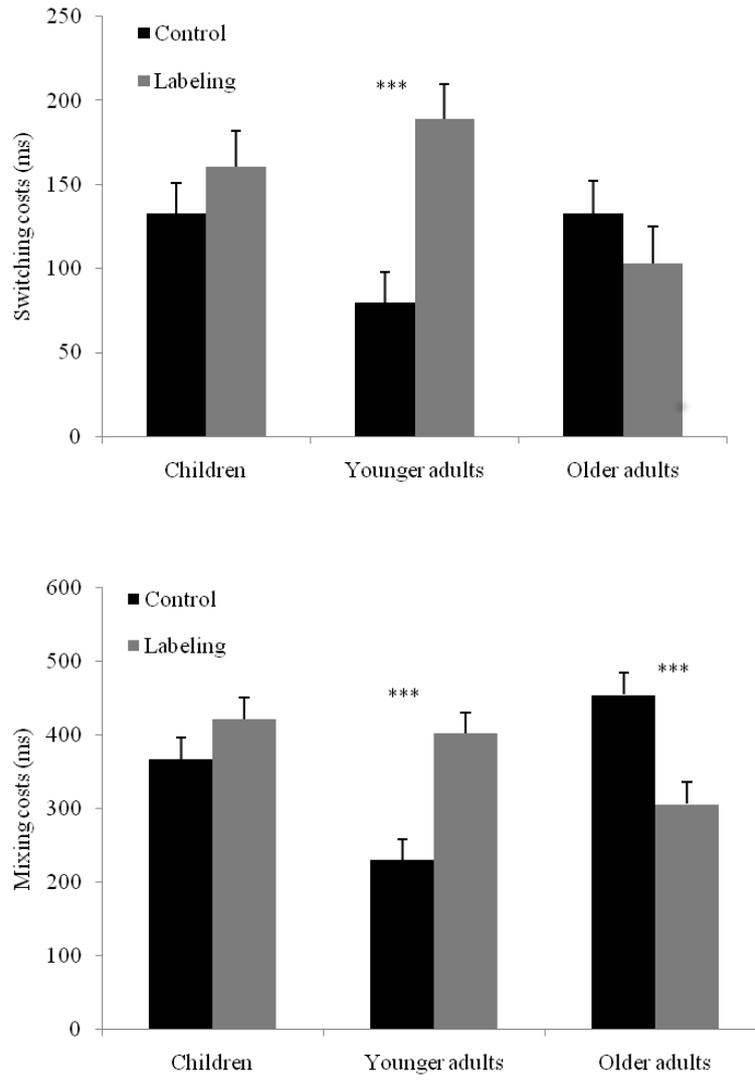


Figure 4. (a) Switching costs and (b) Mixing costs

Table 1. Participants' characteristics

Age group	<u>Children</u>		<u>Younger adults</u>		<u>Older adults</u>	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
n	45		46		41	
Males/females	27/18		16/30		17/24	
Age range	8-9		17-28		64-86	
Mean age	9	.05	22.3	3	70.7	6.5
Years of formal education	-		13.9	2.1	14.1	3
Processing speed test	38.2	7.3	55.1	7.9	42.9	6.5
Working memory test	6	1.2	6.6	2	5.7	1.7
Mill Hill	-	-	22.1	4.3	26.2	5.2