Journal of Experimental Child Psychology 166 (2018) 147–159

Contents lists available at ScienceDirect

Journal of Experimental Child Psychology

journal homepage: www.elsevier.com/locate/jecp

Using language to get ready: Familiar labels help children ~~to~~ engage proactive control

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A R T I C L E   I N F O

Article history:
Received 28 March 2017
Revised 2 August 2017

Keywords:
Executive functions
Proactive control
Cognitive control
Language and thought
Labeling
Visual tracking

A B S T R A C T

A key developmental transition is the ability to engage executive functions proactively in advance of needing them. We tested the potential role of linguistic processes in proactive control. Children completed a task in which they could proactively track a novel (target) shape on a screen as it moved unpredictably amid novel distractors and needed to identify where it disappeared. Children almost always remembered which shape to track, but those who learned familiar labels for the target shapes before the task had nearly twice the odds of tracking the target compared with those who received experience with the targets but no labels. Children who learned labels were also more likely to spontaneously vocalize labels when the target appeared. These findings provide the first evidence of a causal role for linguistic processes in proactive control and suggest new ideas about how proactive control develops, why language supports a variety of executive functions, and how interventions might best be targeted.

Introduction

How do we exercise control to achieve the goals we set out to achieve? Every day we use goals to support flexible behavior, whether we are sticking to a diet, inhibiting emotional outbursts, or switching between tasks to meet looming deadlines. Several decades of research have greatly advanced our

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http://dx.doi.org/10.1016/j.jecp.2017.08.006

understanding of the cognitive processes supporting goal-directed behavior, termed *executive functions,* and indicate they predict success in life across a range of outcomes such as academics, health, and wealth (Mischel, Shoda, & Rodriguez, 1989; Moffitt et al., 2011). As a result, there has been great interest in improving executive functions through interventions; however, so far such efforts have met with limited success (Diamond, 2012; Melby-Lervåg & Hulme, 2013; Shipstead, Redick, & Engle, 2012). A potential reason for the mixed findings is that interventions have not effectively targeted mechanisms and transitions linked to the development of executive functions, in part because there is still much to learn about how executive functions develop. Gaining further insight into processes supporting these developments may be critical to understanding executive functions and improving interventions.

Recent findings point to a developmental transition in the temporal dynamics of how individuals engage executive functions. Across development, children shift from engaging executive functions *reactively,* in the moment they are needed, to increasingly engaging them *proactively,* in anticipation of needing them (Andrews-Hanna et al., 2011; Chatham, Frank, & Munakata, 2009; Chevalier, Martis, Curran, & Munakata, 2015; Lucenet & Blaye, 2013; Waxer & Morton, 2011). For example, on a rainy day, a 5-year-old child may run inside to get a raincoat only after getting wet, whereas a 6-year-old may anticipate the need for a raincoat and prepare by going to the closet to get it before heading outside. Adults flexibly engage executive functions reactively or proactively in response to situational demands, but as they age they increasingly engage executive functions reactively (Braver et al., 2001; Paxton, Barch, Racine, & Braver, 2008). Successful proactive control may depend on abstract goal representations that are supported by sustained activation of the lateral prefrontal cortex, which may be key to efficiently engaging in goal-directed behavior in the context of cognitively demanding events (Braver, 2012; Munakata, Snyder, & Chatham, 2012; Rougier, Noelle, Braver, Cohen, & O'Reilly, 2005).

Language may play a role in the development and engagement of such abstract goal representations (Clark, 2006; Colunga & Smith, 2003). Behavioral studies with children and adults demonstrate that linguistic input plays a key role in the formation of various kinds of abstract representations (e.g., categories, analogical relations) (Loewenstein & Gentner, 2005; Lupyan, Rakison, & McClelland, 2007; Waxman & Markow, 1995; Yoshida & Smith, 2005). Modeling work shows how abstract goal representations that can be maintained in working memory can emerge through experience, including linguistic experience (Rougier, Noelle, Braver, Cohen, & O'Reilly, 2005). Labels are more effective than nonverbal or nonspecific cues in activating abstract representations (Edmiston & Lupyan, 2015). Moreover, consistent with theorizing that language plays a key role in the emergence of higher cognitive functions (Luria, 1961; Vygotsky, 1934/2012), a large body of empirical findings indicates that linguistic processes support executive functions. For example, instructing children and adults to label information relevant to an upcoming task improves task-switching performance (e.g., Kirkham, Cruess, & Diamond, 2003; Kray, Eber, & Karbach, 2008) and action control (Karbach, Kray, & Hommel, 2011). Children also use self-directed speech (overt or covert nonsocial speech) to support performance on planning, delayed recall, and switching tasks (e.g., Fernyhough & Fradley, 2005; Flavell, Beach, & Chinsky, 1966; Karbach & Kray, 2007; Lidstone, Meins, & Fernyhough, 2010). Interfering with such speech (via articulatory suppression) impairs planning and recall in children (Fatzer & Roebers, 2012; Lidstone et al., 2010) and impairs switching in children and adults (Emerson & Miyake, 2003; Fatzer & Roebers, 2012; Kray et al., 2008).

Language may support executive functions by providing information that can be used to engage control proactively (e.g., by preparing for an upcoming task, by verbalizing possible moves in a planning task). Children may use their own speech to maintain task rules or stimulus representations. For example, they may resolve conflict on the Stroop task by verbally representing the goal of responding to the color of a word instead of its meaning in advance of seeing the word. Yet little work has examined linguistic processes in proactive control specifically. One study found that labels designed to encourage proactive control failed to do so in 7- to 10-year-olds (Kray, Schmitt, Heintz, & Blaye, 2015), but children of this age may have already been sufficiently proactive to use their own inner speech without needing labels.

Thus, the current study tested whether linguistic processes play a role in proactive control by manipulating the availability of labels that could be used to support it in 4- and 5-year-old children, who are just developing the ability to engage proactive control on their own (Chevalier et al., 2015;

Lucenet & Blaye, 2013). Children completed Track-It (Fisher, Thiessen, Godwin, Kloos, & Dickerson, 2013), a brief measure that likely taps proactive control (Doebel, Barker, Chevalier, Michaelson, & Munakata, 2017). In this task, children are presented with a target object that moves rapidly on a screen amid distractors and must identify where it disappears. Successful performance seems to require proactively tracking the target, that is, anticipating that the target will disappear and engaging control to track its location beforehand. By contrast, reactive object tracking would involve engaging effort to track an object only after an event has occurred (e.g., seeing a bird fly by and starting to watch it). This kind of tracking is unlikely to help in this task. For example, waiting to see the target moving past would be unlikely to lead to success given all the moving distractors. Similarly, engaging control only after the target is gone is unlikely to support recall of where it was whenever it disappeared. Instead, successful performance seems to depend on proactively engaging control to track the object before it disappears. Consistent with this task analysis, Track-It performance correlates with two existing measures of proactive control even when controlling for age and other possible individual differences; moreover, such relationships with Track-It are specific to indices of proactive control (Doebel et al., 2017).[1]

We randomly assigned children either to learn verbal labels for the targets prior to completing the proactive control task or to receive similar familiarization with the targets in the absence of labels. We equated the conditions on familiarization with the targets given that greater familiarity with stimuli is known to improve performance in multiple object tracking tasks in adults (Oksama & Hyönä, 2008; Pinto, Howe, Cohen, & Horowitz, 2010), and our focus was on the effects of labels. We used novel gray-scale shapes to decrease the likelihood that children would generate their own labels based on familiar shapes and colors, and we used familiar labels that could be mapped onto the novel shapes to increase the likelihood that the labels would provide children with meaningful information they could use to support proactive control via self-directed speech. Although it is possible that nonsense labels could also be used to support proactive control via self-directed speech, the expectation that meaningful labels would help is consistent with prior work on language and executive functions indicating benefits of meaningful verbal information to executive functions (e.g., Emerson & Miyake, 2003; Fatzer & Roebers, 2012; Kirkham et al., 2003; Kray et al., 2008).

We expected that labels could facilitate proactive control by helping children to actively maintain information about the target before it disappeared, possibly via self-directed speech in the form of overt or covert labeling and/or rehearsal of the target's label.[2] Thus, we predicted that children taught verbal labels for the targets would track them more successfully than children not taught such labels.

Method

Participants

A total of 64 4- and 5-year-old children (M_{age} = 5.23 years, SD = 0.41, range = 4.67–6.06; 38 boys) were recruited from a database of families who had previously indicated interest in participating in child development research. An additional 3 children were excluded due to uncooperativeness (n = 2) or experimenter error (n = 1). Data were collected between November 2015 and March 2016. For 92% of our participants, at least one parent had a 4-year college degree, and the remaining 8% completed high school and some college. The racial makeup of the sample was 91% Caucasian, 6% biracial or multiracial, 1.5% African American, and 1.5% American Indian/Native Alaskan. The ethnic makeup of the sample was primarily non-Hispanic/non-Latino (97%).

[1] Whereas the preparatory engagement of control may often occur in the absence of a target stimulus in proactive control tasks, proactive control can also occur when the stimulus is present. Specifically, proactive control involves maintaining goal-relevant information in anticipation of cognitively demanding events (Braver, 2012). In the case of Track-It, whereas the target shape is present during most of the task, children must proactively maintain the goal of identifying the shape's last location in preparation for its disappearance (see also Stedron, Sahni, & Munakata, 2005, for a related example of working memory engagement even when all elements of a task are visible).

[2] Prior work suggests that children do not spontaneously rehearse before 7 years of age (Gathercole, 1998); however, more recent findings suggest that children can rehearse as early as 5 years of age (Doebel, Andersen-Green, & Munakata, 2017).

Design

We employed a between-subjects experimental design, randomly assigning children to one of two conditions: (a) an experimental condition in which children were provided with familiar labels for the novel shapes (Label condition) and (b) a control condition in which children were familiarized with the novel shapes but no familiar labels were provided (Familiarization Only condition). All children then completed Track-It. Gender and age were balanced across conditions (Label: M_{age} = 5.29 years, SD = 0.43; 14 girls and 19 boys; Familiarization Only: M_{age} = 5.18 years, SD = 0.40; 12 girls and 19 boys). Data collection was stopped when the prespecified target sample size of 64 children was achieved (due to an error in condition assignment, the Label condition ended up with 2 more participants than the Familiarization Only condition). A power analysis informed by previous effect sizes was not possible due to a lack of precedent for this specific experimental manipulation in the literature; therefore, we targeted a sample size that was feasible given constraints on the age range suitable for the proactive control measure and the availability of child participants. All administered conditions and measures are reported in this article.

Procedure

The study proceeded in three phases: (a) a pretest phase in which children received experimenter-guided experience with three novel shapes (depicted on 3 × 4-in. laminated cards); (b) a test phase in which children completed the proactive control task, Track-It; and (c) a posttest recall phase in which children in the Label condition were tested on their ability to recall the labels for the novel shapes. Fig. 1 illustrates the pretest and test phases. Track-It is an open-source task and can be accessed online (https://github.com/JohnDickerson/TrackIt). The experimenters were not informed of the study hypothesis.

Pretest phase

Label condition. The child sat across from the experimenter at a small table, and the experimenter placed a card depicting a novel shape on the table (Fig. 2, Shape A), centered in front of the child and oriented to the child's perspective, and said, "Look! This is a *boot,* with a heel here and toe here. Can you say 'boot'? Okay. Let's look at another one." The experimenter then presented the second novel shape (Fig. 2, Shape B) and said, "Look! This is a *dog,* with a nose here. Can you say 'dog'? Okay. Let's look at another one." Next, the experimenter presented the third novel shape (Fig. 2, Shape C) and said, "Look! This is a *goldfish,* with a tail here and head here. Can you say 'goldfish'? Okay. Let's look at another one." The experimenter then repeated the entire procedure one time. Pointing to specific locations on the shapes while introducing the labels enhanced the likelihood that children would grasp how the labels could be applied to the novel shapes and that they were not arbitrary. No children in the Familiarization Only condition spontaneously vocalized the familiar labels that were used in the Label condition, suggesting that these were not obvious labels for the shapes.

Next, the experimenter administered 12 recognition trials with feedback in which the experimenter asked the child to identify one of two novel shapes corresponding to a specific label. The experimenter placed two of the three novel shapes on the table, centered in front of the child, and said, "Now look at these two. Can you point to the [target label]?" If the child was correct, the experimenter pointed to the target shape and said, "Good job, that's a [target label]. Let's look at some more." If the child was incorrect, the experimenter pointed to the target shape and said, "Actually, this one's a [target label]." Four trials per novel shape were administered. The target's appearance on the left or right was counterbalanced across trials, and each target shape was paired twice with each of the remaining novel shapes. The order of presentation was pseudorandom with the constraint that children were not tested for recognition of the same target twice (or more) in a row.

Familiarization only condition. This condition was designed to closely match the Label condition in all respects except that children were not provided with labels for the novel shapes. As in the Label condition, the experimenter sat across from the child and placed a card depicting a novel shape on the table. Instead of introducing the novel shapes with a label, the experimenter said (while pointing to

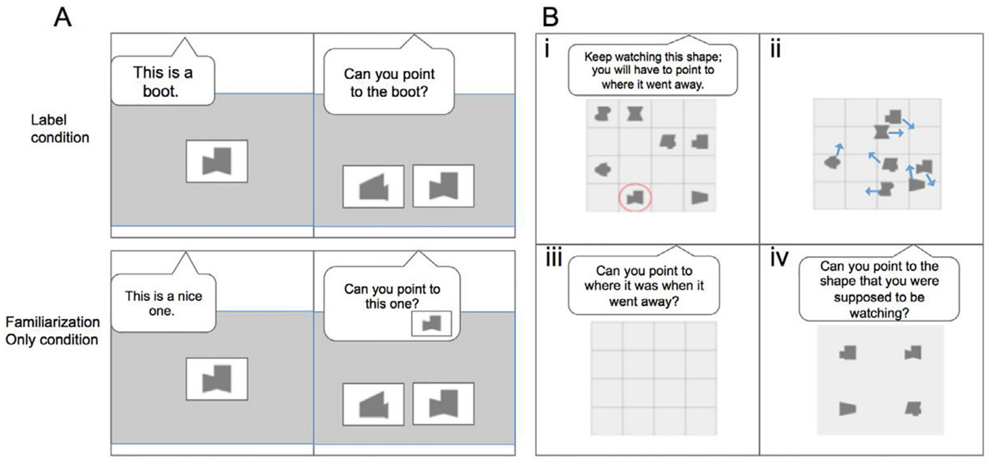

Fig. 1. Schematic of procedure. (A) Children were familiarized with three novel shapes with or without meaningful labels (one familiarization is depicted) and were asked to pick out each novel shape from a pair of novel shapes. (B) Children then were then asked to track a moving target shape (i) as it moved on a random path for approximately 10 s among distractors (ii), report where it was when it disappeared (iii), and indicate which shape they were supposed to track (iv).

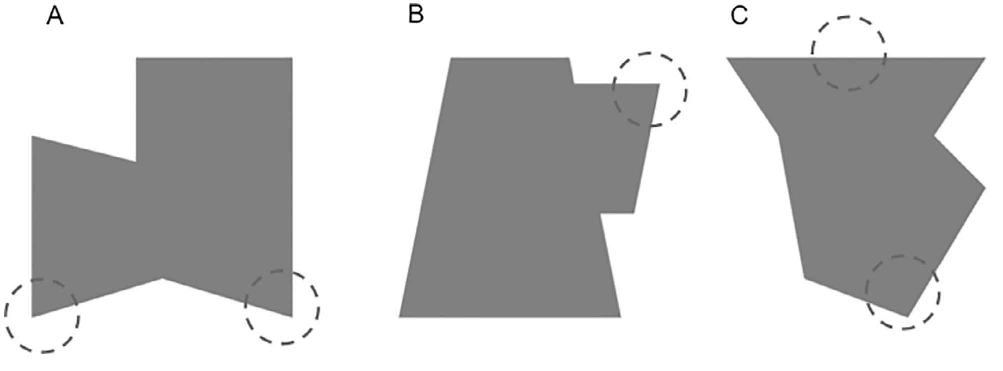

Fig. 2. Novel shapes with which children were familiarized prior to completing the proactive control task in which these shapes then needed to be tracked. In the Label condition children learned familiar labels for these shapes (''boot,'' ''dog,'' and ''goldfish'' for Shapes A, B, and C, respectively), whereas in the Familiarization Only condition they were familiarized with the shapes but did not learn any specific labels for them. Dashed line circles indicate locations to which the experimenter pointed in both conditions when talking about the shape.

the same locations on shape as in the Label condition), ''Look! This is a *nice one*, look here and look here. Do you think it's nice? Okay. Let's look at another one.'' The pointing procedure ensured that children focused their attention on the same regions of the shape as children in the Label condition (Fig. 2). We elected to use ''nice one'' on all three trials to minimize the possibility that children would use the verbal information provided as informative labels to facilitate tracking (e.g., ''nice one'' vs. ''ugly one''). The novel and distractor shapes were designed so that they were distinct (some had rounded edges, some were symmetrical, some had convex angles, etc.) to mimic the distinctness of familiar shapes and to minimize the possibility that children would construe them as being tokens of the same category.

Next, the experimenter administered 12 recognition trials with feedback. This procedure was identical to that described for the Label condition except that, instead of asking the child to identify the novel shape corresponding to a specific label, the experimenter held up a card depicting a novel shape that matched one of the shapes depicted in the two cards on the table and said, "Now look at these two [experimenter motioned to the two cards on the table]. Can you point to this one [experimenter pointed to the card in hand]?" The experimenter continued to hold up the card for the child to see until he or she responded. If the child responded correctly, the experimenter said (motioning to the target shape), "Good job, that's the one. Let's look at some more." If the child was incorrect, the experimenter said, "Actually, this is the one." As in the Label condition, trials were pseudorandom, children needed to identify each novel shape four times, and each shape was paired with each of the remaining novel shapes two times.

Test phase

Introduction to the proactive control task. In this modified version of Track-It, the child was presented with a 4 × 4 grid on a computer screen that was populated by seven novel shapes in grayscale (Fig. 1). The child was instructed that he or she needed to keep watching a target shape as it moved across the grid among the other moving shapes and that all of the shapes would disappear and the child needed to point to the screen where he or she last saw the target shape. Prior to the first trial, the experimenter pointed to the shape on the screen that had a red circle around it (e.g., Fig.2A) and said, "We are going to play a game where you need to keep looking at this one right here. It will move all over the screen for a little while. The other shapes will be moving too. Your job is to keep looking at this one. The shapes will all go away and you'll have to point to the screen where this one was right before it went away. So keep looking at this one. Okay?"

Demonstration trial. At the beginning of the first trial, the experimenter said, "This time we are going to do it together. I will follow it with my finger this time so that you can see what shape I'm watching." When the shapes disappeared, the experimenter moved the finger away from the screen and said, "Can you point to where it was when it went away?" If the child was correct, the experimenter said, "Good job, this is where it was at the end—right before it went away. So I will press the screen right here." If the child was incorrect, the experimenter said, "Actually, the one I was watching went away right here, so I will press right here." Demonstration trials were not repeated.

Memory check. After each proactive control trial, the experimenter assessed the child's recognition memory for the target the child was instructed to track on the preceding trial. The child was presented with a 2 × 2 matrix of four shapes, one of which was the target and the other three of which were among the distractors. The experimenter said, "Okay. Now can you point to the shape that you were supposed to keep watching?" Children were given corrective feedback on the demonstration trial but not on subsequent trials.

Test trials. At the beginning of the test trial, the experimenter said, "Okay. Let's do it again. But this time, you'll play by yourself! And this time, your job will be to look at a different one. You'll have to keep watching this one, but use your eyes only—no finger. Okay? Keep watching this one." After the shapes disappeared, the experimenter said, "Okay, can you point to where it was when it went away?" For a response to count as accurate, the child needed to clearly point inside the same square in which the target had landed. If a child's point was ambiguous, the experimenter asked the child to point again so that the experimenter could see where the child was pointing. The experimenter then tapped the screen to record the response (as in Fisher et al., 2013).

Children completed a total of 14 trials, 9 of which were test trials and 5 of which were "filler" trials. On test trials, the target shape was one of three shapes from the pretest phase for which children were taught labels (Label condition) or with which they were familiarized (Familiarization Only condition). Filler trials involved novel target shapes that were not among those presented in the first phase of the experiment and were included to space out the presentation of the test trials and reduce the possibility that children in the Familiarization Only group might, as a result of repeated experience with the same shapes, spontaneously develop their own labels for the test trial target shapes. In total, children saw each of the novel target shapes three times. The order in which the shapes were presented was fixed and pseudorandom, such that the same target was not presented more than once every three trials. The same six distractor shapes (shown in Fig. 1), not shown prior to the Track-It task, were used on every trial.

The speed of target and distractor objects was set to 600 pixels per second at 30 frames per second. The target and distractor objects subtended approximately 2.8° of the visual angle at a viewing distance of 60 cm. These parameters, along with the number of distractors, were selected based on prior published work and pilot data suggesting that they would produce a level of difficulty that avoided floor and ceiling effects in this age group (Doebel et al., 2017). The targets and distractors moved on linear paths as in Fisher et al. (2013) and mimic the default object movement settings of the Track-It software. Objects started in the center of 1 of the 12 squares in the grid (with no objects starting in the same square) and then moved randomly to different squares until the minimum trial length was surpassed. The end location of the target was also random. Targets needed to visit each of the 12 cells and needed to be positioned in the center of a given cell before disappearing. Trials lasted a minimum of 10 s; however, actual trial length varied slightly to adhere to the motion restrictions (Fisher et al., 2013). With the specified parameters, the task is reproducible via the GitHub codebase. A movie of the task can be found at https://osf.io/ywf8t/. Additional details regarding the task can be found at https://github.com/JohnDickerson/TrackIt. Parameters for this specific task are directly available in a commit to that codebase.

In addition to recording children's accuracy on the tracking and memory trials, the experimenter noted whether children spontaneously and audibly verbalized a label on each Track-It trial. If a label was vocalized, the experimenter noted what label was used.

Posttest phase

After completing Track-It, children in the Label condition were briefly tested on their recall of the labels they had previously learned for the novel shapes. The experimenter showed the child a single shape and asked, "What's this one called?" The child did not receive feedback. The child completed nine pseudorandom trials, three trials per novel shape.

Analytic approach

We modeled our data using mixed-effects logistic regression, implemented via the lme4 package in R (Bates, Mächler, Bolker, & Walker, 2015). Logistic regression was selected because our dependent variable, Track-It trial accuracy, was binary and linear models violated the assumption of normally distributed errors that underlies linear regression. A mixed-effects model was selected because our dependent variable (successful tracking of a target shape on a given trial) was measured within subjects, and modeling within-subjects error increases the reliability of parameter estimates (Judd, McClelland, & Ryan, 2011). Fixed effects tested in our models were condition, age, memory for the target on a given trial, and spontaneous vocalization of labels during test trials. Random intercepts for individual participants were included in all models to address dependence among Track-It test trials measured within subjects and to account for individual differences in accuracy on those trials. Maximum-likelihood estimation was used to estimate the most probable parameters given the model, and log likelihood ratio tests were conducted to test single parameters by comparing nested models (where the more complex model included one more parameter than the simpler model), with a significant chi-square (χ^2) statistic indicating improvement in model fit. Results are presented as odds ratios, that is, the increase in the odds of an accurate response on Track-It associated with a unit increase on a given model parameter. Rerunning analyses excluding observations that were larger than 3 standard deviations beyond the mean Cook's *D* value did not change the results. No data were excluded from reported analyses. The complete R script used to run these analyses can be found online (https://osf.io/q9f5c).

Results

We first report the results of the simplest mixed regression model (i.e., with condition as the only fixed effect) before reporting the same model with covariates added.

As predicted, children in the Label condition ($M_{accuracy}$ = .34, *SD* = .24) outperformed children in the Familiarization Only condition ($M_{accuracy}$ = .23, *SD* = .21) in tracking novel shapes, odds ratio (*OR*) = 1.89, χ^2 = 4.70, *p* = .03, 95% confidence interval (*CI*) [1.06, 3.39] (Fig. 3).[3] That is, the odds of tracking the target in the Label condition were nearly two times the odds in the Familiarization Only condition. Children in the Label condition had no difficulty in remembering the labels they were taught for the novel shapes. Only 1 child out of 33 children erred, responding to two of nine recall questions incorrectly.

The effect of condition held when controlling for children's memory for the target, *OR* = 1.87, χ^2 = 5.20, *p* = .022, 95% *CI* [1.04, 3.33]. Children in both groups showed little difficulty in remembering which shape to track (Label: *M* = 90%, *SD* = 10%; Familiarization Only: *M* = 87%, *SD* = 15%), consistent with previous findings using other versions of this task (e.g., Fisher et al., 2013) (Fig. 4). Children performed more poorly on trials where they forgot which shape they were supposed to track regardless of condition, *OR* = 4.19, χ^2 = 12.48, *p* < .001, 95% *CI* [1.71, 10.29]. The effect of condition also held when controlling for children's age, *OR* = 1.72, χ^2 = 3.74, *p* = .053. Age independently predicted Track-It trial accuracy when controlling for condition, *OR* = 1.54, χ^2 = 9.50, *p* = .002, 95% *CI* [1.17, 2.01], such that the odds of successfully tracking the target were 1.5 times greater as age increased by 1 standard deviation. The effect of condition also held and was marginally significant when controlling for both age and memory, *OR* = 1.70, χ^2 = 3.56, *p* = .059, 95% *CI* [1.04, 2.80].

We also explored the possibility that labels for the target shape made children more likely to spontaneously vocalize, which helped them to track the shape. More children in the Label condition (12 of 33) than in the Familiarization Only condition (3 of 31) spontaneously vocalized labels for the target shapes on a portion of the test trials, χ^2 = 5.23, *p* = .022. Children in the Label condition vocalized labels that were consistent with what they were taught (e.g., saying "goldfish" when the corresponding target shape appeared), whereas children in the Familiarization Only condition made up their own labels ("maze," "camera," etc.). Of the 12 children in the Label condition who vocalized labels for the targets on the test trials, 4 also vocalized made-up labels for the targets on filler trials. We compared a model that included all of the data and condition, age, memory, and spontaneous vocalization (present vs. absent) as predictors with a model that did not include vocalization and did not find evidence of improved model fit with vocalization included as a predictor, χ^2 = .01, *p* > .250. The same comparison including only data from the Label condition yielded comparable results, with no evidence that spontaneous vocalized labeling facilitated tracking in that condition over and above age and memory. These findings are not unexpected given that children who did not vocalize may have used inner (silent) speech to support proactive control.

An exploratory analysis indicated that the pattern of results was similar when all trials (test trials and filler trials) were included in the analysis, potentially because children generalized from their pretest experiences to other stimuli (e.g., with children in the Label condition generating labels for filler trials). Trial accuracy did not differ significantly by trial type, *OR* = 1.29, χ^2 = 2.24, *p* = .13, 95% *CI* [0.92, 1.77]. There was no interaction between trial type and condition, *OR* = .84, χ^2 = .27, *p* = .60, 95% *CI* [0.43, 1.61]. Condition was still a significant predictor of trial accuracy when the filler trials were included in the analysis, *OR* = 1.83, χ^2 = 4.04, *p* = .04, 95% *CI* [1.02, 3.38]. The pattern did not change when accounting for variability due to trial type, *OR* = 1.83, χ^2 = 4.04, *p* = .044, 95% *CI* [1.02, 3.29].

We also tested an alternative hypothesis about how labels might have facilitated proactive control via improvements in motivation. Differential motivation across conditions could have resulted from children finding the task more fun and engaging when they could track dogs, boots, and goldfish or from children perceiving the Label condition as a teaching situation. If so, children in the Familiarization Only condition should have performed worse as the trials progressed; however, we did not find evidence that this was the case. In a linear regression that tested the effects of trial number, condition, and their interaction, we found that across conditions children performed slightly better as the trials increased, *B* = .012, *p* = .01, and there was no interaction with condition, *p* = .244.

[3] The results of our primary analysis testing our key hypothesis were the same when alternative statistical analyses were used: independent *t* test, *t*(62) = 2.045, *p* = .045; Wilcoxon rank sum test, *W* = 356, *p* = .036.

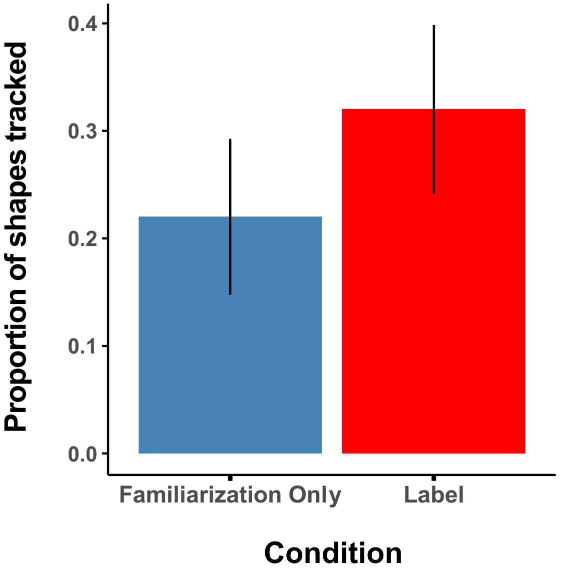

Fig. 3. Children were more accurate in tracking shapes after learning labels for them, consistent with labels supporting proactive control. Error bars represent 95% confidence intervals.

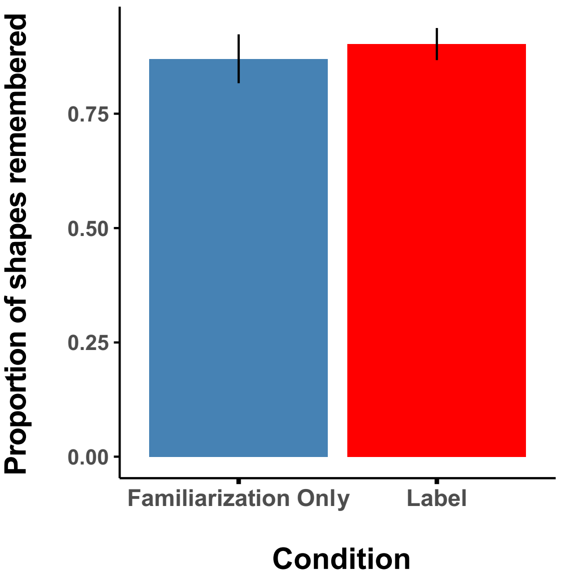

Fig. 4. Children were highly and comparably accurate in remembering the shapes they were supposed to track across conditions, so the benefit of the labels cannot be explained by any influence on children's ability to discriminate the target from other shapes presented during the trial. Controlling for memory for the target did not change the results.

Discussion

This study is the first to indicate a role for linguistic processes in proactive control. Providing children with familiar labels for novel targets facilitated tracking of the targets in the face of distractors in a task that likely requires proactively tracking targets in advance of their disappearance (Doebel et al., 2017). Labels may have supported proactive maintenance of target representations via self-directed speech, reducing the likelihood of attention being captured by the distractors. For example, on seeing the target at the onset of a test trial, children may have said the label to themselves (overtly or covertly), supporting proactive tracking of the target before it disappeared. The finding that children in the Label condition spontaneously vocalized the labels during the test trials more than children in the Familiarization Only condition is consistent with this interpretation. In addition, children in the Label condition may have spontaneously generated labels to facilitate the tracking of target shapes in the filler trials. Although spontaneous vocalization did not predict tracking accuracy, the increased presence of such speech when labels were provided is consistent with the possibility that other children were labeling covertly via inner speech. Differences between conditions did not appear to be driven by differences in motivation.

Labels may have supported proactive control via additional pathways. For example, familiar labels may have supported performance on Track-It by helping children to form more detailed visual representations of the target shapes (e.g., by allowing children to interpret the novel shapes as exemplars of familiar concepts). Such strengthening of object representations might influence proactive control by making it easier to maintain the representations in mind across time and facilitating proactive tracking of the shapes amid distractors. Conversely, the Familiarization Only condition may have led to complementary impairments to object representations; children might have treated the targets and distractors as tokens of the same category after hearing a subset of these shapes described as "nice," which may have impeded their ability to form individualized representations of the targets that could support tracking. In this way, we view such potential changes to object representations as inherently intertwined and interacting with control and other core cognitive processes (Lupyan & Swingley, 2012; MacDonald & Christiansen, 2002; Samuelson & Smith, 2000; Shinskey & Munakata, 2003; Vales & Smith, 2015), as opposed to occurring in isolation. From this perspective, other ways of making the targets distinct could similarly aid proactive control performance—teaching children to view the targets as agents, for example. The relative effectiveness of such potentially nonlinguistic approaches could be tested in future work.

Our finding that familiar labels supported proactive control performance raises broader implications about development, language and executive function, and interventions. First, linguistic processes may play a role in the development of proactive control. Children's use of self-directed speech to support executive functions develops with age (Alderson-Day & Fernyhough, 2015), and this speech may support proactive control specifically. Self-directed speech (e.g., labels, rehearsed items, task rules) may support proactive control by helping children to form and actively maintain robust, abstract goal-relevant representations in working memory (Munakata et al., 2012). With age, children may more routinely and spontaneously use labels and other self-directed speech to support proactive control, especially if they notice the benefits of such speech to task performance.[4]

Linguistic processes may also play a role in the decline of proactive control with age. Older adults tend to rely more on reactive versus proactive control than younger adults (Braver et al., 2001; Braver, Satpute, Rush, Racine, & Barch, 2005; Paxton et al., 2008) and, like children, they are less likely to spontaneously use self-directed speech to support performance on cognitive tasks such as task switching (Kray et al., 2008) and ordered recall (Murphy, Schmitt, Caruso, & Sanders, 1987). Insofar as self-directed speech on executive function tasks could be supporting proactive control specifically, declines in such speech could reduce proactive control and result in broader executive function deficits.

Given these benefits of labels on proactive control functioning, we speculate that the well-established benefits of language in tasks requiring executive functions (e.g., Emerson & Miyake,

[4] We note that this characterization is compatible with research indicating that language can sometimes hurt performance on cognitive control tasks; in those cases, language may also enhance representations but of information that supports incorrect responses (e.g., Kray et al., 2015; Yerys & Munakata, 2006).

2003; Fernyhough & Fradley, 2005; Flavell et al., 1966; Kirkham et al., 2003; Kray et al., 2008; Lidstone et al., 2010) could reflect, at least in part, the benefits of language to proactive control. Performance across many tasks could benefit from the proactive engaging of executive functions in advance of needing to use them. For example, proactive maintenance and rehearsal of task-relevant information could improve performance in ordered recall, planning, and switching tasks (Alderson-Day & Fernyhough, 2015). Proactive control is also important in aspects of executive function where the need for proactive processes may be less apparent such as inhibitory control (Chatham et al., 2012; Chevalier, Chatham, & Munakata, 2014; Hampshire, Chamberlain, Monti, Duncan, & Owen, 2010; Sharp et al., 2010).

The current findings suggest that interventions aimed at improving executive functions in children and adults could target linguistic processes that can potentially be used to support long-term changes in proactive control. Specifically, our results show that providing familiar-label training prior to the target task (as opposed to within the task at the moment it is needed) improves proactive control. Prior work indicates that labels can be provided to change executive function performance in the moment, whereas the current work suggests that labels can be used to support longer-lasting change. Labels provided in the moment or in advance of a task may operate via the same pathway (e.g., facilitating self-directed speech used to maintain the task goal or changing how the shapes are represented). Future work can build on these findings to test whether linguistic training could support even longer-term changes in proactive control.

Future research can also further test the breadth of effects of linguistic manipulations. For example, the benefit to proactive control functioning in our study may have been specific to the labeled targets, or it may have generalized beyond them to induce broader changes in proactive control functioning. The latter possibility is consistent with our finding that children showed similar benefits from being in the Label condition regardless of whether a particular target was labeled (as on target trials) or not labeled (as on filler trials), but further work is necessary to rigorously test the question of breadth.

In addition, the benefits from familiar labels might not have been limited to proactive control functioning. Our hypothesis about the effects of labels on proactive control was theoretically and empirically motivated. However, as with any experimental manipulation, it is possible that labels improved aspects of Track-It performance that were not related to proactive control given that any task designed to measure a specific construct will also capture task-specific variance (e.g., demands on motor control, memory, comprehension). Consistent with prior work indicating a role for language in a range of cognitive processes, labels might have also improved performance on other potential measures such as recalling the target shapes after a long delay or in a particular order. We tested the possibility that labels influenced general task motivation or memory for the target shape and did not find evidence of this. Future research could further address this issue by including multiple measures of proactive control and a latent variable approach to extract common variance that could be influenced by labels.

Our finding that language supports proactive control functioning in children suggests that linguistic processes could play a key role in the engagement and development of abstract representations that support proactive control and executive functions more broadly. Although other interpretations of our results are possible, our study provides a confirmatory test of our hypothesis and can serve as a foundation to address remaining questions in future studies like those we have proposed. Targeting linguistic processes in proactive control may be a fruitful direction in interventions to improve executive functions across the lifespan.

Acknowledgments

This research was supported by the Eunice Kennedy Shriver National Institute of Child Health and Human Development of the National Institutes of Health under Award No. F32HD079191. The authors thank Jessica Craver for assistance with data collection, Eliana Colunga for suggestions on the design of the experiment, and members of the Cognitive Development Center for comments on an earlier version of the manuscript.

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