Relations Between Developmental Transitions in Proactive Control and Self-Directed Speech

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Senior Honors Thesis

January 25th, 2017

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In addition, many thanks to Dr. Sabine Doebel, my post-doctoral mentor for this project.

Abstract

Executive functions (EFs) are mechanisms that help us regulate our thoughts, feelings and behaviors; and predict important life outcomes. EFs go through a developmental transition in childhood, from reactive control to proactive control. A parallel transition to this transition occurs in self-directed speech, which is also used to guide, plan and to support self-regulation of cognition and behavior. This cross-sectional study tested whether there is a relationship between developmental transitions in children's use of self-directed speech to regulate their behavior and the proactive engagement of executive functions. Five to seven-year-old children (*N* = 82) completed measures of proactive control and self-directed speech. Proactive control and self-directed speech changed with age. However, these transitions did not appear to be related, potentially due to issues of small sample size and the number of tasks. Other limitations included the inability to test causal interpretations. These limitations suggest the need for further research to test relations between these transitions and causal relationships.

Key words: Self-directed Speech, Proactive Control, Executive Functions

Relations Between Developmental Transitions in Proactive Control and Self-Directed Speech

A hallmark of human cognition that has been widely researched is the ability to regulate and control our cognition and behaviors. We exercise control over our thoughts and actions every day, in order to reach our goals and fulfill our plans, for example, by resisting temptations in order to stick to a diet, waking up instead of sleeping in, paying attention at an important meeting, and flexibly switching between thoughts in order to remember deadlines. Unlike adults, children are notorious for their failure in self-regulation and inhibition. Children are known for their inability to resist temptations (Miyake, Friedman, Emerson, Witzki, Howerter, & Wager, 2000), such as candy, and their inability in inhibiting impulses, which can result in socially inappropriate behavior (Miyake et al., 2000), like telling a person that he or she does not like their Christmas present. As children get older they increasingly stay alert in school and remember to pay attention when crossing the street (e.g., Chevalier & Blaye, 2016).

Skills that help children overcome their problems with self-regulation and inhibition by regulating their cognition and behaviors are termed *executive functions* (EFs). EFs are processes that help children with planning, inhibition, switching and with working memory (e.g., Chevalier, Martis, Curran & Munakata, 2015; Lucenet & Blaye, 2014). They are goal-directed behaviors that regulate, coordinate and guide children’s thoughts and behaviors. EFs play a role in various cognitive and social skills such as language, theory of mind and emotion regulation (Carlson & Moses, 2001; Clarson & Wang, 2007; Deák, 2003). EFs develop dramatically in childhood and predict important outcomes later in life (e.g., academics, social skills, health, and wealth; Mischel, Shoda,

& Rodriguez, 1989; Moffitt, Arseneault, Belsky, Dickson, Hancox et al., 2011). Due to this important role of executive functions, further research on EFs would be beneficial.

A pivotal qualitative and quantitative change in EFs in early childhood is in the temporal dynamics of how EFs are engaged, from reactive control to proactive control. Adults can flexibly shift between engaging in EFs reactively or proactively, while young children are biased to engaging in EFs reactively (Chatham, Frank, & Munakata, 2009; Chevalier, James, Wiebe, Nelson & Espy, 2014). However, a change in how children engage proactive control seems to emerge between 5 and 6 years of age: children shift from reactively engaging EFs as needed in the moment (e.g. standing and waiting under a roof because of the rain) to increasingly proactively engaging them in expectation of needing to use them (e.g. bringing an umbrella in anticipation of the impending rain). Three-year-olds engage control reactively (Chatham, Frank, & Munakata, 2009), while 5-year-olds can use or be encouraged to use proactive control (Chevalier, Martis, Curran & Munakata, 2015; Lucenet & Blaye, 2014). Six-year-olds show evidence of costs and benefits of proactive control (Blackwell & Munakata, 2014) and continue to show improvements in proactive control (Lucenet & Blaye, 2014).

A parallel transition occurs in children’s use of self-directed speech used to guide, plan and to support self-regulation of cognition and behavior (Winsler & Naglieri, 2003; Alderson-day & Fernyhough, 2015; Fernyhough & Fradley, 2005). It is thought to be an almost universal feature of the development of young children (Alderson-day & Fernyhough, 2015, Fernyhough & Fradley, 2005). Between the ages of 3 and 8 years, children transition from using audible task-irrelevant speech (e.g. self-directed speech not relevant to the current situation), to audible task-relevant speech (e.g. audible, selfregulating comments relevant for the current task), to external manifestations of inner speech (e.g., inaudible muttering that cannot be deciphered) (Alderson-Day & Fernyhough, 2015).

These key developmental transitions in EFs and self-directed speech may be related. A relationship might exist since both of these transitions occur during the same time window and because self-directed speech aids EFs (Alderson-Day & Fernyhough, 2015; Cragg & Nation, 2010), which could occur through its support for proactive control. Consistent with this idea, self-directed speech seems to support EFs in tasks where the need to actively maintain information across time is high (e.g., Fatzer and Roebers, 2012). On the other hand, proactive control might support private speech. For example, children who can anticipate the need for control may utter task-relevant information to themselves in preparation for future responses. Finding a relationship between these two transitions could provide further insight into proactive control and the processes supporting EFs, and inform future studies testing causal questions and implications for intervention.

To date there have been no studies examining whether these transitions are related, which is the goal of the current study. Specifically, this study will test whether changes in self-directed speech are correlated with improvements in proactive control, and if this relationship holds when controlling for IQ. Controlling for IQ provides some assurance that a relationship between these two processes is not due to proactive control and self-directed speech covarying with IQ in participants. This study is a cross-sectional correlation study, which will test for a correlation between 5 to 7-year-old children’s performance on measures of proactive control and self-directed speech. I predict that there will be age-related changes in proactive control and self-directed speech, such that there will be an age-related improvement in proactive control use and a transition in the usage of self-directed speech types. I further predict that children's performance on measures of proactive control and self-directed speech will be positively associated.

Methods

Participants

Ninety children were recruited from a database of families who indicated interest in participating in child development research. Most of the participants were white and from middle to high socioeconomic backgrounds, which reflects the surrounding local communities neighboring Boulder, Colorado. The mean age of participants was 6 years and the age range was 5 years to 7 years. Of these children, 9 were excluded for the following reasons: uncooperativeness (*n* = 2), failure to successfully complete the practice phase of the delayed recall task (*n* = 2) or the cued-task switching task (*n* = 2), developmental delay (*n* = 1), and video recording failure (*n* = 2). The experimenter obtained parent's informed consent before participation. After completing each session, each child received a small age-appropriate prize for participating (a toy or a book), and the parents received $5.00 compensation for their travel expenses.

Materials and Procedure

A trained experimenter tested each of the children individually. The experiment consisted of two 60-minute sessions held approximately a week apart. Children completed three tasks: 1) a cued task-switching measure 2) a delayed visual serial recall task, and 3) the Kaufman Brief Intelligence Test (KBIT). These tasks were a subset of tasks administered in a larger study investigating relations between transitions in proactive control and private speech. To minimize variation between subjects in task performance due to differences in order, the task order was fixed. The cued switching task was the primary measure for proactive control, and the delayed recall task was the primary measure for self-directed speech. The KBIT was used to measure IQ.

Cued task-switching paradigm (Chevalier et al., 2015). This task was introduced to the children as the “Santa Claus Game” in which they were instructed to help Santa prepare for next Christmas. They were asked to sort toys (i.e. the targets) by their shape or color. These sorting types were labeled as the “shape game” and the “color game”, respectively. The toys consisted of two combinations of shapes and colors: a blue/red bear or car and a green/orange airplane or doll. During each trial, children saw an 8cm x 8cm target (e.g., an orange doll) on the computer screen encircled by a cue (a black circle) signifying the appropriate sorting category (see Figure 1). The black circle containing gray geometrical shapes cued the shape task and a black circle containing patches of different colors cued the color task. Children were instructed to look at the circle to know which game to play (shape or color game) and respond by pressing the appropriate button on a response pad as fast as possible. The horizontally aligned buttons on the response pad were labeled with 4 one-dimensional pictures of either combination (e.g., an airplane, a green patch, a doll, and an orange patch). These pictures were also displayed on the computer screen directly below the target. On each trial, the children were first shown an empty circle containing a fixation cross, which was replaced by a gift box. This gift box was replaced by the target, which remained on the screen until a response was pressed.

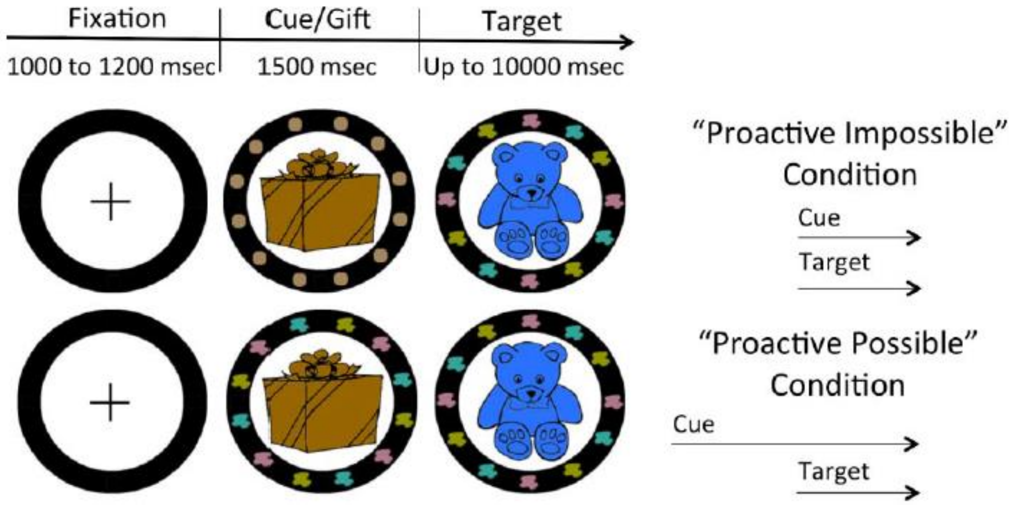

Figure 1. Diagram for cued task-switching paradigm. Black circle containing splotches of colors was the cue, which cued the child to sort the toy (target) by color. In the Proactive Impossible condition cue was shown at the same time as the target. In the Proactive Possible condition cue was shown before the target.

The experimenter explained the rules of each sorting game to the child. Explanations were followed by four practice trials in which the experimenter helped the children by asking them which game was being played and what button should be pressed. The first four practice trials were either only color trials or shape trials. Next the experimenter explained to the child that they needed to look at the cue to know which game to play, because the two sorting games were going to be played at the same time. This was followed by an additional set of four practice trials, in which the experimenter helped the children by asking them which game was being played and what button should be pressed. Experimenters provided corrective feedback and practice trials were repeated if the wrong response was pressed. The test phase consisted of 30 trials, in which no corrective feedback was provided.

This task consisted of two conditions: the Proactive-Impossible condition and the Proactive-Possible condition, which differed in the timing in which the circle containing the cues was presented. The dependent measure for this task was how fast children respond when they had the opportunity to prepare (i.e. Proactive-Possible condition), controlling for their performance when they could not proactively prepare (Proactive-Impossible condition). In the Proactive-Impossible condition, children saw the task cue at the same time as the target, which made it impossible for the children to proactively prepare. In the Proactive-Possible condition the children saw the task cue before the target was shown and remained when the target appeared. This gave the children an opportunity to proactively prepare their responses.

Delayed recall task (adapted from Flavell, Beach, & Chinsky, 1966). The goal of this task was to remember the order of three pictures, which were presented one at a time. At the beginning of this task the children were shown all of the pictures used in this task and were asked to overtly name each picture. This was followed by two practice trials in which the experimenter pointed to three pictures with their finger and asked the child to verbally reiterate the previously presented order. These practice trials were followed by three additional practice trials in which the child was able to practice the actual recall game. In these practice trials, the child saw three pictures consecutively appear on the computer screen one at a time, with a two second interval between them. This was followed by an eight-second-delay period in which the child saw a black screen with a white fixation cross in the middle of the screen. This was followed by screen in which the child saw all three pictures at the same time in a random order (see Figure 2). Children were asked to point to the pictures in the order they first saw them in, using a stick with a rubber end so that it was clear to the experimenter where they were pointing. The experimenter recorded the child's responses. The practice trials were repeated once if the child inaccurately responded during these trials. If children continued to respond incorrectly, but randomly (i.e., not consistently pointing to the pictures from left to right) then they progressed to the test phase of the task.[1] The successful completion of the practice trials was followed by 10 test trials, in which the child did not receive corrective feedback.

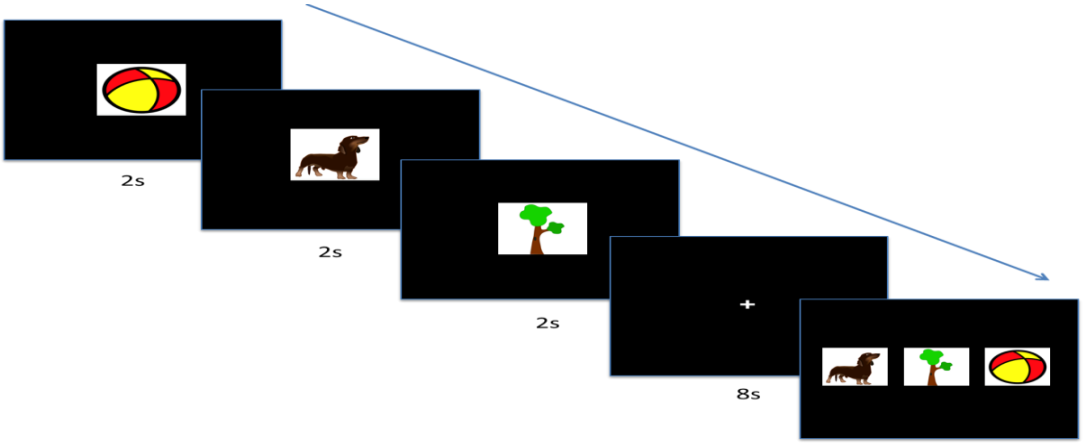

Figure 2: Schematic diagram of delayed recall task. Children saw three pictures appear on the screen one at a time, which was followed by an 8-second delay. During the 8-second delay the children saw a black screen with a white fixation cross in the middle. This delay was a followed by a screen portraying all three pictures at the same time.

The Kaufman Brief Intelligence Test; Second Edition (KBIT) (Kaufmann and Kaufmann 2004). This test provided a quick measure of verbal and nonverbal intelligence in children. The test consisted of three subtests, two of which were Verbal sets and one was a Nonverbal set. Across all three subtests, children were able to earn a score of 1 (pass) or 0 (fail) for each item they completed in the subset. A subset was discontinued if the child responded to four consecutive items incorrectly. While the children responded the examiner recorded the responses on a record form. While the

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[1] Children who do not use a strategy such as rehearsal during the delay interval would be expected to perform poorly during the practice phase and thus would not be excluded, whereas children who consistently respond by pointing to the pictures from left to right would be demonstrating failure to understand the task instructions.

examiner read out the instructions, the child was shown a selection of possible responses on an easel. Each page of the KBIT consisted of colored pictures of which the children were able to choose their response.

The first verbal subtest, Verbal Knowledge, was made up of 60 items. During this task the examiner either said a word or a phrase and the children were instructed to choose a picture out of six possible answers that best described the word or phrase. For example, the child was instructed, "Point to the one that goes with thunder [child proceeded on pointing to a picture of lightning]." This subtest did not contain any teaching and practice items.

The second subtest was Matrices and consisted of 46 items, divided into three different types of tests, each of which became progressively harder. The objective of this subtest was to find a relationship or rule in a set of pictures or patterns. The children were either instructed to point to a picture that was related to a given picture or to find a missing piece in a certain pattern. For example, children saw a picture (e.g. a car) placed above five other pictures lined up in a row (e.g. a truck, a frying pan, a sun, fruit, and a zipper), which were all one-dimensional. The child was instructed, "This one [experimenter points to car] goes with one of these [i.e. experimenter gestures across the row of pictures]. Point to the one that goes with this one [i.e. experimenter points back to the car]." Before the first item, the child completed a sample and practice item in which the experimenter gave corrective feedback. In another example, the children saw a 3 x 3 grid in which the middle piece was missing. Underneath this grid, the children saw a row of 6 pictures of possible options. Their objective was to complete the pattern by selecting a picture of the 6 possible options.

The third subtest was Riddles and consisted of 48 items. In items 1-8, the experimenter told the child a verbal problem and the child was instructed to point to a picture that showed the best answer. For example, “Point to something that is sweet and made with milk.” For items 9 to 48, the examiner read a verbal problem in riddle format to the child and the child was told that the answer was only one word. For example, “What is very far away, can only be seen at night and twinkles in the sky? [Child responded with ‘stars’].”

Self-directed Speech Coding and Transcription

Transcription. The primary measure of self-directed speech was the delayed recall task. Performance on this task was videotaped with a camera that was stationed in the room with the experimenter and child, and was focused on the participant. The speech the child used during the task was transcribed verbatim.

Coding. For the first level of coding, a blind coder transcribed each trial for the presence or absence of speech on this task by re-watching the video files gathered from each session. If speech was present they differentiated between self-directed and social speech. Self-directed speech is speech uttered to oneself and social speech is speech uttered to another person, which often results in a response. The blind coder also differentiated between whispering/mumbling/lip movement and overt speech.

For the second level of coding, a blind coder coded all of the first level coding data and a second coder coded 25% in order to establish inter-rater reliability. Correlations between the rater's coding ranged from r = .94 to .99, indicating high inter-rater reliability. Discrepancies were resolved through discussion. Unlike in the first level coding, the coders did not use video footage, but the coding data collected from the first level coding. The coders recorded the number of trials on which there was overt speech, partially covert speech, labeling and rehearsal. Labeling and rehearsal might be expected to aid performance on this task due to encoding the necessary information into working memory, which in return would aid in the retrieval of this information.

Analytic Approach

A subject and trial-level regression analyses was used. In a subject-level analysis the child's performance on a task was predicted. For example, a subject-level analysis predicted the amount or type of self-directed speech the average child used on the delayed recall task. In a trial-level analysis the performance on a trial was predicted. For example, a trial-level analysis predicted the reaction time, the dependent measure, on the cued task-switching paradigm in the Proactive Possible condition. In the trial-level analysis, the subject-level variance in performance was still accounted for, by modeling unique intercepts (means) for each participant.

Results

Descriptive Statistics

Participants were faster in the Proactive Possible condition than in the Proactive Impossible, suggesting that they engaged proactive control (Table 1). Accuracy was generally high, suggesting that children understood the task (Table 1).

Table 1

Range of Accuracy, Mean of Accuracy and Mean Reaction Time in Proactive Possible and Proactive Impossible Condition

Measure	*Proactive Possible*	*Proactive Impossible*
Range of accuracy	*.5 to 1*	*.53 to 1*
Mean accuracy	*.86*	*.89*
Mean reaction time	*2.2 sec*	*2.7 sec*

To get an understanding of how often self-directed speech was used and what type, means of all of the types of self-directed speech were calculated. As seen in Table 2, in most trials no speech was used, and overt and covert speech were used almost equally as often. Also, 52 children used some speech on some trials, 47 children did not use any overt speech, 38 children did not use any partially covert speech, 41 children did not use any labeling and 38 children did not use any rehearsal.

Table 2

Percentage (%) of Trials in which Types of Self-Directed Speech (SDS) was used and Number of Children who used Types of Self-Directed Speech

Measure	*Overt speech*	*Covert speech*	*No Speech*	*Labeling*	*Rehearsal*
% of trials	*.27*	*.28*	*.45*	*.28*	*.26*
Number of children	*34*	*43*	*29*	*40*	*43*

Changes with Age

There was a significant age-related improvement in proactive control in the Proactive Possible condition, $b = -20.76$, $SE = 8.69$, $X^2 = 5.52$, $p = .02$.[2] With each unit (month) increase in children's age, their reaction time decreased by 20.76 milliseconds.

A linear model was conducted to test whether age predicts individual differences in self-directed speech (Table 3). A significant age related change in overt speech, labeling and rehearsal was found. As children got older they used less overt speech and less labeling, but more rehearsal and marginally more covert speech (Figure 3).

Table 3

Age-related Change in Self-Directed Speech (SDS)

Type of Self-Directed Speech	*r*	*df*	*t*	*p*
Overt	*-.22*	*79*	*-2*	*.05*
Covert	*.2*	*79*	*1.79*	*.08*
Labeling	*-.27*	*79*	*-2.52*	*.01*
Rehearsal	*.25*	*79*	*2.31*	*.02*

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[2] No scatter plot was provided because the data is trial-level data, which does not lend itself well to plotting.

Age-related Change in Self-Directed Speech

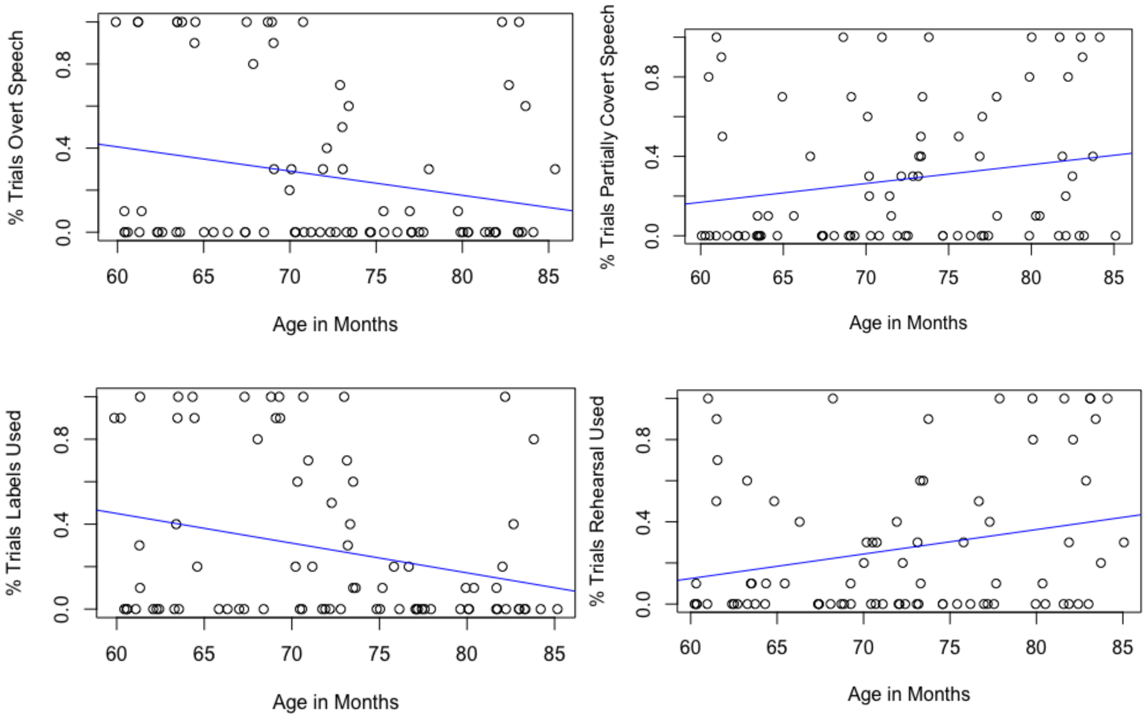

Figure 3

Exploratory analyses, to test whether self-directed speech plays a role in the delayed recall score, revealed that partially covert speech and rehearsal predicted performance on the delayed recall task (Table 4), while labeling and overt speech did not (Figure 4).

Table 4

Does Self-Directed Speech Predict Recall Performance

Type of Self-Directed Speech	*df*	*r*	*p*
Rehearsal	*77*	*.28*	*.01*
Labeling	*77*	*.07*	*.52*
Overt speech	*77*	*.04*	*.74*
P. Covert speech	*77*	*.32*	*.004*

Does Self-Directed Speech (SDS) Predict Recall Performance?

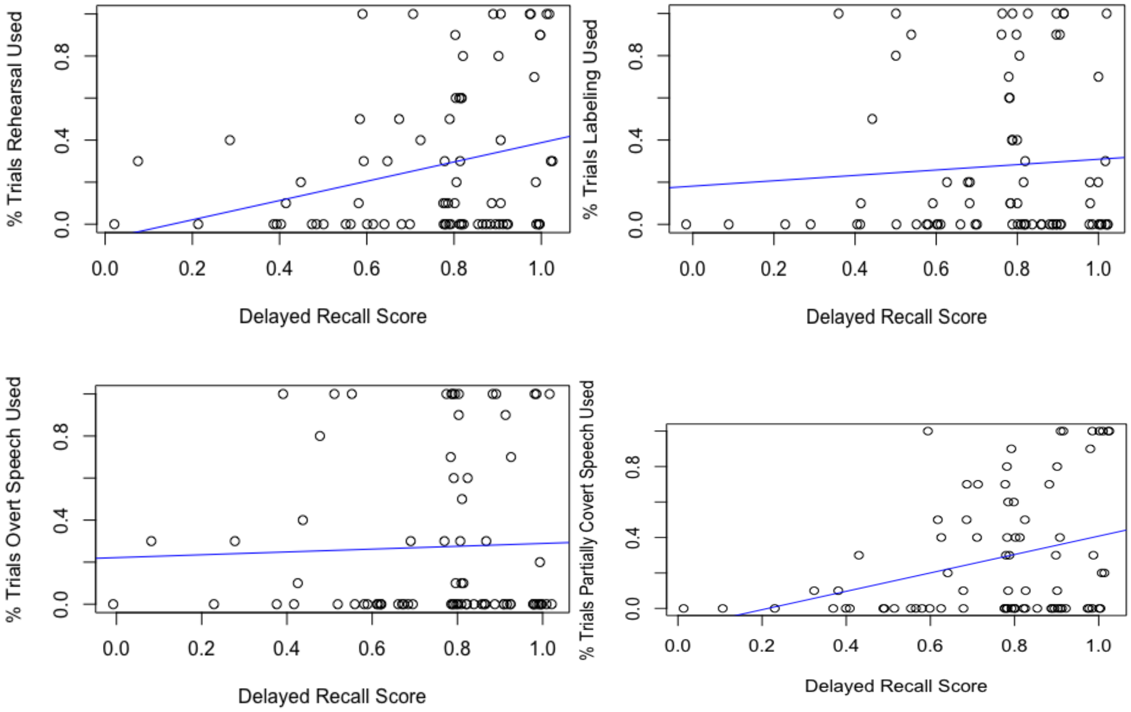

Figure 4

The relationships between the delayed recall score and speech were the same when controlling for age, and in addition it revealed a significant relationship between delayed recall score and no speech. Specifically, when controlling for age, partially covert speech, rehearsal and no speech predicted delayed recall performance, while labeling did not (Table 5).

Table 5

Does Self-Directed Speech Predict Recall Performance, when Controlling for Age?

Type of Self-Directed Speech	*F*	*df*	*b*	*p*
P. Covert speech	*4.48*	*2 and 76*	*-.0015*	*.01*
Rehearsal	*3.41*	*2 and 76*	*-.0013*	*.04*
No Speech	*3.72*	*2 and 76*	*.0009*	*.029*
Labeling	*.297*	*2 and 76*	*.0015*	*.74*

While some forms of speech predicted delayed recall performance, age did not, *p* = 0.8, *r*(77)= .029.

Relations Between Transitions

Contrary to my prediction, individual differences in proactive control did not predict individual differences in self-directed speech. The predictors of percentage of trials on which child used overt speech, partially covert speech, labeling and rehearsal were not significant predictors of proactive control performance (Table 6).[3] Therefore, individual differences in self-directed speech were not a significant predictor of individual differences in proactive control performance. No significant relationship between proactive control performance and self-directed performance was found.

Table 6

Individual differences in Proactive Control did not Predict Individual Differences in Self-directed Speech

Type of Self-Directed Speech	*b*	X^2	*p*
Overt speech	*51.8*	*.12*	*.73*
P. Covert speech	*-200.38*	*1.36*	*.24*
Labeling	*9.85*	*.004*	*.95*
Rehearsal	*-150.19*	*.74*	*.39*

These findings did not change when controlling for IQ and age (Table 8). IQ was a marginally significant predictor of proactive control, *b* = -6.46, $X^2 = 3.5$, *p* = .06. IQ was not associated with any of the measures of self-directed speech (Table 7).

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[3] No scatter plot was provided because the data is trial-level data, which does not lend itself well to plotting. The dependent variable was performance on a given trial, which did not lend itself to plotting in a scatter plot.

Table 7

IQ is Not a Predictor of Self-directed Speech

Type of Self-Directed Speech	*F*	*DF*	*p*
Labeling	*.12*	*1 and 75*	*.73*
Rehearsal	*.09*	*1 and 75*	*.76*
Overt speech	*1.21*	*1 and 75*	*.27*
Covert speech	*1.28*	*1 and 75*	*.26*
No speech	*.003*	*1 and 75*	*.96*

Table 8

Controlling for IQ and Age

Type of Self-Directed Speech	*b*	X^2	*p*
Overt speech	*-97.99*	*.4*	*.52*
P. Covert speech	*-92.17*	*.3*	*.58*
Labeling	*-140.92*	*.8*	*.37*
Rehearsal	*-53.35*	*.1*	*.76*

Discussion

This study is the first to examine a relationship between developmental transitions in proactive control and self-directed speech. Age-related changes in proactive control and self-directed speech were found, but there was no evidence of a relation between these two transitions.

As predicted, proactive control develops with age, which was shown through a decrease of reaction time in the Proactive Possible condition as children got older, consistent with previous work finding that 8-year-olds show proactive maintenance while 3.5-year-olds did not (Chatham, Frank, Munakata & Carey, 2009), that 5 year old can use or be encouraged to use proactive control (Chevalier, Martis, Curran & Munakata, 2015 and Lucenet & Blaye, 2014) and that 6 year olds show improvements in proactive control (Lucenet & Blaye, 2014).

Also as predicted, self-directed speech changed with age, which was shown through age-related changes in overt speech, labeling and rehearsal, consistent with previous findings (e.g., Al-Namlah et al., 2006; Fernyhough & Fraley, 2005).

Not only did self-directed speech go through a developmental transition but some facets of self-directed speech also predicted recall performance. The results showed that even after controlling for age, rehearsal and partially covert speech predicted recall performance. These findings are interesting in the context of the absence of findings of a relationship between proactive control and self-directed speech. Rehearsal and partially covert speech are preparatory processes for the later task of recalling the order, which may be very similar to engaging proactive control. Like rehearsal and partially covert speech, proactive control prepares the child for the later task. This analysis might predict a relationship between delayed recall, self-directed speech and proactive control. Although a relationship between self-directed speech and delayed recall was found, no relationship between self-directed speech and proactive control was found.

Results also showed a marginal relationship between IQ and proactive control. This finding is interesting in the context of the result that there is no relationship between IQ and self-directed speech. IQ is an evaluation of one’s ability to reason, think and find solutions for problems. EFs are processes that help children regulate, coordinate and guide thoughts and behaviors. Since EFs helps children coordinate their thoughts it may be more directly related to IQ. Unlike EFs, self-directed speech helps with planning and organizing (Cragg and Nation, 2010). Self-directed speech gives the children an ability to guide and control their behavior, which in return can aid in cognition but may be less directly related to cognition than IQ. This lack of relationship might also be due to the transitions in self-directed speech being an almost universal phenomenon that occurs in most children, no matter what their intelligence level is.

Individual differences in self-directed speech were not a significant predictor of individual differences in proactive control performance, even after controlling for age and IQ. These findings suggest that the transitions in self-directed speech and proactive control may not be related, but there may be other reasons why a relationship was not found. The current study used only one measure for each of the primary constructs, proactive control and self-directed speech. This, along with the sample size, may have affected the power to detect significant results because the measures may not have been sensitive enough. Future research could combine across multiple measures to reduce noise in measurement and achieve greater power to detect effects. Additionally, more participants could help to increase power. For example, adding more participants to this existing data would give the researchers more data to work with and will increase the probability to correctly reject the null hypothesis.

This study also did not allow for causal interpretations, which could be addressed in future research. For example, the current study did not research the causes of the age-related transitions in proactive control and self-directed speech, but only looked at if they exist and if they are related. Future research could address this limitation by researching the causes of these transitions and their potential relationship. It could also investigate the causes of targeting and manipulating either proactive control or self-directed speech, and its impact on the other. For example, future research could manipulate either proactive control or self-directed speech to test for causal relationships between proactive control and self-directed speech. Future research could inhibit the child's ability to either use proactive control or self-directed speech, and measure the changes in the other construct. Changes in the other construct could suggest causal interpretations and relationships.

Conclusion

The current study found age-related improvements in proactive control and some changes in self-directed speech, consistent with prior research. Results also showed that some facets of self-directed speech predicted recall performance, which was an interesting finding because no significant relationship between these transitions was found. Future research could resolve the limitations of the current study and could potentially find a significant relationship between these transitions. Due to the importance of executive functions and self-directed speech in our life, the topic of this research could be very important to the research community and could have a big impact on our understanding of executive functions and their relationship with other transitions.

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