Executive function development

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Executive Function Development:

Making Sense of the Environment to Behave Adaptively

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Abstract

Emerging executive function in childhood, one of the main predictors of major life success, is goal-directed in nature. Yet, children's ability to identify goals (i.e., what should be done) has been under-researched, often implicitly assuming that it is trivial even in early childhood. In contrast, I review evidence for goal identification as a major force behind developing executive function. Both increasing attention to environmental cues and increased goal inferencing from these cues drive goal identification improvement with age. This framework has important implications for assessing and supporting childhood executive function.

Keywords: executive function, cognitive control, goals, cues, cognitive development, children.

Executive function development:

Making sense of the environment to behave adaptively

Young children are not good at self-regulating. They are prone to tantrums, are all "over the place" and fail to focus their attention. Yet, they are already expected to control their thoughts and actions, and emerging executive function, which supports such control, predicts life success (e.g., Moffitt et al., 2011). For instance, in the classroom, children need to follow instructions, raise hands before talking, take turns, etc. To accomplish these actions, they must identify what the goal is and what actions they should take to reach it. The goal (i.e., the intention to achieve a task, an action, or a state; Altmann & Trafton, 2002) is maintained in the prefrontal cortex and guides actions by biasing activity in posterior brain regions (Miller & Cohen, 2001). Therefore, executive function is goal-directed in nature; it cannot be exerted without a goal to reach. It primarily serves the intentional pursuit of explicit goals, although some goals or "drives" may arise and influence behavior out of consciousness without necessarily involving executive function (Custers & Aarts, 2010).

In short, having a goal is key to goal-directed behavior. As mundane as this statement may sound, until recently, goal identification had been largely under-investigated in childhood, perhaps because of early action-knowledge dissociations (e.g. 3-year-olds can say how to play a game but fail to actually play it; Zelazo, Frye, & Rapus, 1996), even though dissociations are only apparent and disappear when knowledge and action measures are matched in complexity (Munakata & Yerys, 2001). Goal identification is conceptually distinct from the processes responsible for reaching it, such as attention reorientation, response selection, or motoric stopping (e.g., De Baene & Brass, 2014). Most research to date has focused on those other processes and goal maintenance and shown their role in executive function

development (e.g., Aron & Poldrack, 2006; Kirkham, Cruess, & Diamond, 2003; Miyake & Friedman, 2012; Munakata et al., 2011). Until recently little was known, however, about goal identification, perhaps because goal identification was implicitly assumed to be trivial even for children, who were thought to know what they should do but fail to do it.

I propose that children also often fail to identify relevant goals. Goal identification failures are distinct from, though conceptually related to, goal neglect (i.e., failed goal maintenance in working memory), whose role has long been recognized (e.g., Kane & Engle, 2000). Oftentimes children do not just forget what they should do, they never figure it out. Specifically, I propose that with age children pay greater attention to cues in the environment and process them more effectively to identify goals, which, in turn, better guide the control of thoughts and actions (Figure 1).

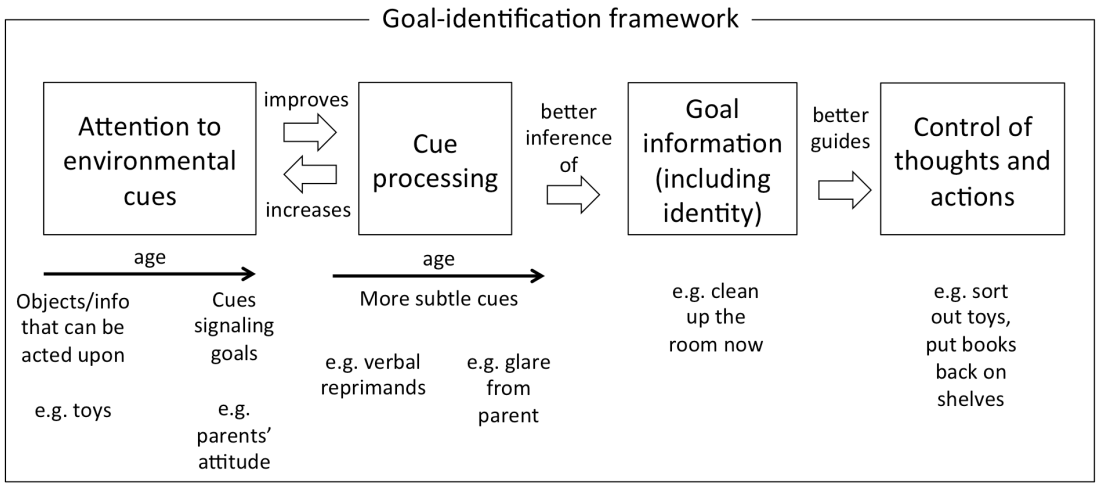

Figure 1. Goal-identification framework. Young children tend to prioritize objects that they can directly manipulate over environmental cues. With age, children pay increasing attention to cues, which improves cue processing to identify the relevant goal and goal-related information (e.g., when to pursue the goal). Reciprocally, better cue processing encourages them to pay even more attention to cues. Although closely

related, the two changes are distinct. Attention to cues is necessary but not sufficient to ensure that children infer all possible information from the cues if, for instance, children do not yet use inner speech to translate cues into goals (see Cragg & Nation, 2010). (For example, children already gaze at cues consistently by age 6, but still infer goals more easily from more transparent cues until age 9 (Chevalier & Blaye, 2009; Chevalier et al., 2015).) Finally, identified cues guide the control of thoughts and actions.

INCREASING ATTENTION TO ENVIRONMENTAL CUES

In most situations, we determine which goal to pursue and actions to take based on cues available in our environment. For instance, a green traffic light signals that one should go, a nudge that one should stop talking, a student's puzzled face that a concept should be explained differently. Young children, however, may not be as sensitive as adults to environmental cues, resulting in failures to identify relevant goals. Specifically, early in life, children seem to prioritize environmental information or objects that they can directly manipulate, even if they do not know how to act upon these objects efficiently, leading them to overlook environmental cues signaling the relevant goals. With advancing age, they may instead progressively look for environmental cues because they progressively learn their meaning and can use it to determine what they should do (i.e., how to act efficiently on objects).

Support for such a shift in processing priority comes from eye gaze trajectories in the task-switching paradigm. This paradigm (Meiran, 1996) is particularly appropriate to study goal identification because it involves changing task goals on multiple occasions. Specifically, children are asked to switch between two tasks (e.g., sorting a target by color or shape) as a function of task cues (e.g., a star

besides the target signals it should be sorted by color, whereas a circle signals the target should be sorted by shape). Task uncertainty (due to unpredictable task changes) makes goal identification especially taxing (Rubin & Meiran, 2005).

Six-year-old children and adults fixate the task cue before gazing at the target, which is the most efficient trajectory because the cue signals whether to process the target color or shape. Four- and 5-year-olds, by contrast, gaze first at the target and response images (with which the target has to be matched), that is, the information that is directly tied to actions to be made and that they ultimately need to respond to. These children either completely ignore the cue or fixate it only after they looked at the target and response images. Indeed, young children's prioritization of the target over the cue is so pervasive that they ignore the cue even when it is presented ahead of the target, looking instead at the empty area where the next target will appear (Chevalier, Blaye, Dufau, & Lucenet, 2010; Chevalier, Dauvier, & Blaye, 2015). Consistently, when asked to "think aloud", 5-year-olds more often label the target or responses and less often the cue, compared with 9-year-olds (Karbach & Kray, 2007).

If young children struggle to identify the relevant goal because they tend to prioritize the target over the task cue, encouraging them to process the cue before the target should enhance their performance. Consistently, 5-year-olds respond faster and show event-related potential and pupil dilation markers of early cue processing when the early-presented task cue disappears before target onset to encourage cue-then-target processing (Chevalier, Martis, Curran, & Munakata, 2015).

Prioritizing information/objects that can be directly acted upon over cues is probably adaptive in early childhood because young children actually benefit from *little* executive function. This proposal relies on a simple tradeoff: by guiding actions in a top-down fashion, goals both sharpen behavior *efficiency* and reduce the *variety*

of behaviors that can be implemented. Bottom-up, data-driven behaviors mediated by posterior regions support richer object manipulations and exploration of the environment than prefrontally-mediated, goal-directed behaviors. Rich object manipulations support extracting statistical regularities in the environment, which is important for other cognitive acquisitions such as language and social conventions (Thomspon-Schill et al., 2009). Later in childhood, the importance of learning statistical regularities declines while increasing need for autonomy calls for more efficient behaviors ensured by the top-down influence of prefrontally-mediated goals (Chrysikou, Weber, & Thompson-Schill, 2013; Thompson-schill, Ramscar, & Chrysikou, 2009). At that age, therefore, actively looking for cues becomes increasingly critical as it allows correct goal identification.

The mechanism driving the shift in the type of information prioritized during childhood is only speculative at this point. However, it is plausible that, as children gain experience with their environment, they progressively learn to associate specific objects or situation features with specific functions and behaviors—a process that is not executive in nature—and to better use these associations to predict the most appropriate goals and actions when they subsequently encounter similar features, which now serve as cues. Therefore, with age and increasing experience with the environment, children may progressively learn the meaning of cues, which leads them to pay increasing attention to them. Reciprocally, as they pay increasing attention to cues, they may accumulate knowledge of cue meanings and which information serves as a cue for specific goals and actions.

BETTER PROCESSING OF ENVIRONMENTAL CUES

As children start to pay increasing attention to environmental cues, they progressively learn to extract goal information more efficiently. Processing cues is

challenging, though, because cues tremendously vary in nature and transparency. Some cues strongly signal what to do (e.g., answer when the phone rings) while others less clearly so (e.g., shall I leave the building as the fire alarm goes off or is it just the monthly alarm check?). Goal identification is especially difficult when cues are arbitrarily related to tasks, as is the case of widely used preschool measures such as the Shape School and Advanced DCCS, perhaps because arbitrary cues require verbal mediation to be translated into goals (e.g., Miyake, Emerson, Padilla, & Ahn, 2004; Logan & Schneider, 2006).

Young children struggle to identify goals from arbitrary cues that provide only little external support for these goals (even if they can perfectly recall their meaning). In the task-switching paradigm, 5-year-olds' performance can be considerably improved by replacing traditional arbitrary cues (e.g., a black square for color matching and a gray circle for shape matching) with transparent cues that are easier to translate into a task goal (e.g., a rainbow for color and a shape sorter for shape, Chevalier & Blaye, 2009). This effect is substantial in magnitude (about 15-point difference in percent correct) and robust across studies (Blaye & Chevalier, 2011; Chevalier & Blaye, 2009; Chevalier, Wiebe, Huber, & Espy, 2011; Towse, Lewis, & Knowles, 2007). By ages 7 and 9, children's performance becomes progressively less dependent on cue transparency, suggesting important improvement in cue processing and goal identification (Chevalier & Blaye, 2009).

It is well established that young children, especially those with lower working memory capacity, often fail to maintain relevant goals (e.g., Chevalier & Blaye, 2008; Marcovitch, Boseovski, Knapp, & Kane, 2010; Marcovitch, Boseovski, & Knapp, 2007). Conversely, they also struggle to detect *when* to update the goal. Providing 5-year-olds with additional information about when to change tasks, through transition

cues such as the word “different” when a task switch is expected, enhances task-switching performance (Chevalier, Huber, Wiebe, & Espy, 2013; Chevalier et al., 2011). Interestingly, children can benefit from transition cues even if they do not know their meaning, as shown by similar performance gains with arbitrary transition cues (e.g., “kopo” for task change and “jada” for task repetition) whose meanings they cannot recall (Chevalier et al., 2011). Therefore, semantic processing of cues is not always necessary because the breaks in the perceptual flow of information generated by transition cues is enough to help children detect the need to do something different, just like a loud or weird sound may attract attention away from the goal one is pursuing.

Similarly, many situations require detecting that a goal or action is no longer relevant, as when an ongoing action should be inhibited. This is the case, for example, when a child about to hit a classmate suddenly realizes that an adult is watching and completing the action may get them in trouble. Although actually stopping the motoric action has traditionally been considered the bulk of response inhibition (e.g., Aron & Poldrack, 2006), detecting the cue that signals hitting should be cancelled (the adult watching) is just as critical. Indeed, practicing cue detection without motoric stopping subsequently enhances response inhibition in 7- to 9-year-olds to an even greater extent than motoric-stopping practice with minimal cue detection demands (Chevalier, Chatham, & Munakata, 2014; see also Winter & Sheridan, 2014).

As children grow older, they successfully infer goal information from increasingly subtle cues (Chevalier & Blaye, 2009; Chevalier et al., 2013). Yet, cue processing and goal identification never become trivial, even for adults whose reaction times are still influenced by cue transparency (Chevalier & Blaye, 2009; Logan & Schneider, 2006; Miyake et al., 2004). Indeed, cue processing may even

remain the most challenging process underpinning adulthood response inhibition (e.g., Chatham et al., 2012).

Importantly, increasing attention to environmental cues combined with greater ability to extract goal information from cues may impact profoundly how children exert control. Specifically, they may contribute to the progressive shift from reactive to proactive control after 6 years of age (Chatham, Frank, & Munakata, 2009; Chevalier, James, Wiebe, Nelson, & Espy, 2014; Lucenet & Blaye, 2014; Munakata, Snyder, & Chatham, 2012). Reactive control is engaged transiently, in the moment, to resolve the interference between several conflicting tasks or responses (e.g., figuring out the way while already walking). In contrast, proactive control is engaged ahead of time, by anticipating and preparing for predictable, upcoming interference in order to prevent its detrimental effect on cognition and behaviors (e.g., looking up directions before walking to a new place; Braver, 2012). Because proactive control often requires anticipating future events based on early cues, greater attention to and inference of more information from cues (e.g., cue reliability) with age may contribute, with other factors such as increasing working memory capacity, to promoting proactive control.

In summary, with advancing age, children pick up increasingly diverse and subtle cues in their environment, which helps them to identify more easily what they need to do and gradually use this goal to guide actions (Chevalier et al., 2012). For instance, a glare from parents is now enough for children to understand that they need to clean up their room, when explicit reprimands used to be necessary. As cue processing improves, children are more likely to infer richer information. Children may infer not only goal identity and when to change it, but also which goals are worth pursuing based on predictions of how much effort each needs and how to best exert

control to attain it (see Shenhav, Botvinick, & Cohen, 2013), potentially resulting in more strategic allocation of control with age. Finally, cue processing and goal identification may not be tied to specific aspects of executive functions (updating, inhibition, switching), and thus they may help clarify what "common" executive abilities are (Miyake & Friedman, 2012).

CONCLUSION

The goal-identification framework has important implications for both assessing and supporting childhood executive function. First, assessing goal identification may clarify a child's specific executive profile and difficulties, in particular whether the child struggles with processes responsible for goal identification, goal attainment, or both. Goal identification may contribute to a child's difficulties especially in tasks where goals and when to change them must be inferred based on non-transparent cues (e.g., Counting Creatures of the TEA-Ch) or feedback (Wisconsin Card Sorting Test). Second, this framework suggests that simple environmental manipulations that help children better process cues and identify goals (e.g., more transparent cues, early cue presentation) can effectively enhance children's engagement of executive function on tasks tapping response inhibition and/or set shifting in early and middle childhood, when goal identification is most challenging. Such manipulations are simple, relatively inexpensive, and immediately effective. In addition, training cue processing and goal identification may also be an option of choice to enhance executive functioning as it is potentially more effective than training other executive processes such as motoric stopping.

Important questions remain for future research. In particular, the work reviewed here has focused on external cues. Yet, cues can also be internal (e.g., retrieval of errands to run, emotions, fatigue) but little is known about how children

process internal cues and integrate them with external ones. In addition, not only does cue processing lead to goal identification; but current goals also may reciprocally influence attention to and processing of environmental cues, which should be explored in future studies. Finally, research is needed to determine to what extent the goal-identification framework, which has been developed based on typically developing children, may be insightful for children with developmental disorders.

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