Accepted for publication in Journal of Cognition and Development

A first theoretical model of self-directed cognitive control development

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Abstract

Cognitive control (also referred to as executive functions) corresponds to a set of cognitive processes that support the goal-directed regulation of thoughts and actions. It plays a major role in complex activities and predicts later academic achievement. Importantly, while growing up, children are progressively transitioning from engaging cognitive control in an externally driven fashion, i.e., relying on external guidance, to exerting it self-directedly, i.e., autonomously determining when and how to engage it. Although growing self-directedness in cognitive control engagement is critical to autonomy gains during childhood, relatively little is known about the underlying cognitive mechanisms. Incorporating previous main proposals in cognitive control development, we propose that self-directed control development is driven by the ability to identify relevant goals, facilitated through accumulated knowledge on how to engage cognitive control with age. Importantly, we argue that there are two key processes that are part of successful goal identification: context-tracking and goal selection. We argue that most developmental changes are linked to context-tracking as the demands on this process are particularly high in self-directed situations. We then derived main predictions from this theoretical model as well as promising future directions.

Key words: cognitive control development, self-directed control, theoretical model

Introduction

Children engage cognitive control, also known as executive functions, in many daily activities. As an example, while children are working on homework in the living room, they may need to inhibit the temptation to watch TV (regulation of actions and emotions) in order to focus on completing their school exercises (the goal). This goal-directed regulation of thoughts, actions and emotions (Miller & Cohen, 2001) slowly develops across childhood and predicts academic achievement (Ahmed et al., 2019; Robson et al., 2020; Samuels et al., 2016), income, and health in later life (Moffitt et al., 2011).

Age-related progress in cognitive control throughout childhood has mostly been documented in contexts where control engagement is externally driven, where explicit instructions or environmental cues indicate which goal to pursue, information to focus on, and/or actions to select. For instance, children show increasing ability to switch between different operations in a math exercise based on an explicit instruction given by the teacher (see Doebel & Zelazo, 2015). Indeed, early in childhood, cognitive control engagement is mostly externally driven by caregivers. However, as children grow up and move up school grades, they are increasingly expected to engage cognitive control more self-directedly, that is, without (or at least, with less) explicit instructions or environmental cues. Self-directed control differs from externally driven control in that goal attainment is not driven by extrinsic factors, such as explicit instructions or environmental cues, but by intrinsic factors such as past experiences, fatigue or mood. This form of control, which may be considered especially mature (Munakata et al., 2012), fosters greater autonomy and independence in various contexts and activities. Indeed, time spent in unstructured activities (e.g., free play), where children need to manage their time and activities on their own (i.e., without guidance from adults), predicts performance on measures of self-directed control during childhood (Barker et al., 2014).

Despite its importance in children’s lives, relatively little is known about self-directed control development in childhood. The present paper aims to provide the first theoretical conceptualization of the cognitive processes underlying the development of this form of control during childhood. We begin by arguing that externally driven and self-directed forms of control do not correspond to discrete categories. Instead, we contend that these forms of control are two ends of a continuum. We discuss how current theories of cognitive control speak to the cognitive processes underlying self-directed control development. Then, we propose a tentative theoretical model where we highlight the main cognitive processes at play in the development of this form of control across childhood. We then present some of the predictions deriving from this model before ending by future directions for research.

A continuum rather than discrete forms of control

It has been suggested that with age, children transition from externally driven to self-directed engagement of cognitive control (Munakata et al., 2012). Children consistently perform better concerning tasks that require externally driven than self-directed control. For instance, children between the ages of 3 and 4 can switch back and forth between two rules to sort cards only when an adult explicitly tell them the new sorting rule (Zelazo et al., 1996). However, when they need to infer the sorting rule from a less explicit response feedback, therefore tapping more on self-directed control, only children older than 7 successfully switch between the task, whereas younger children perseverate with the old rule (Jacques & Zelazo, 2005).

The developmental transition from externally driven control to self-directed control echoes Vygotsky’s *internalization* of higher-order cognitive processes such as self-regulation, memory, attention, or language (Vygotsky, 1978). Through internalization, these processes, which are first externally represented by tools, are progressively reconstructed as internal signs, and simultaneously shift from interpersonal to intrapersonal in nature. For example, learning language, a child initially uses language solely to communicate with other people but, once mastered, language become internalized and can be used for self-regulatory purposes through private and inner speech. The transformation of *sign-using (i.e., internal) activities*, to adopt Vygotskian terms, implies that psychological activity varies along a continuum in the extent to which it is internally or externally oriented. In line with Vygotsky, we claim here that, although **s**elf-directed and externally-driven controls have been often implicitly presented as two discrete forms of control (Barker & Munakata, 2015; Munakata et al., 2012), they form a continuum on which the degree of self-directedness (i.e., to what extent a task or an activity is internally oriented) varies (see also White et al., 2009).

Consistent with a continuum between externally driven and self-directed controls, tasks used to assess cognitive control vary in self-directedness demands. For instance, consider the Verbal Fluency task (Troyer et al., 1997) and the Wisconsin Card Sorting Test (WCST; Grant & Berg, 1948). In the former, participants must generate as many items of a given category (e.g., animals) as possible within a fixed period of time. Thus, they must self-directedly detect when a switch to a different subcategory of items is needed to then select to which subcategory of items they should move to. Conversely, in the WCST, participants must discover and switch between sorting rules as a function of response feedback, so the decision of when to switch is indicated by feedback from the experimenter (but not to which card-sorting rule to switch to). Therefore, there is lower self-directedness demands in the WCST than in the Verbal Fluency task.

If self-directed and externally driven controls are different in degrees of self-directedness, but not in nature (i.e., two distinct categories), then they should rely by and large on similar components or processes. Thus, existing theories of (externally driven) cognitive control development may provide insight on self-directed control as well. Therefore, in what follows, we briefly review how the main current theoretical proposals on cognitive control development speak to how cognitive control engagement becomes increasingly self-directed as children grow older.

Self-directed goal identification

Given the goal-directed nature of cognitive control, identifying the goal (*goal identification*) to attain is a prerequisite to successfully guide behavior. In other words, one cannot focus on goal-relevant information, ignore (goal-irrelevant) distraction, and select the most appropriate actions if they have not first identified what goal they should pursue. Indeed, information and action relevance are not absolute but relative to that goal. For instance, children may not pack their climbing shoes for a weekend trip if they do not keep in mind while packing that the trip will include climbing activities. By nature, self-directed and externally driven forms of control differ in how goal identification is achieved. When control is externally driven, the ability to identify goals is achieved through contextual cues that signal how to behave efficiently (e.g., tapping foot from parents to indicate to turn off the TV; (Miller & Cohen, 2001), whereas no such contextual cues are available when control must be engaged self-directedly. This likely accounts for the greater difficulty of self-directed control. According to the goal-identification framework (Chevalier, 2015), progress in cognitive control during childhood is largely driven by increasingly efficient goal identification with age, which in turn relies on greater attention to processing and monitoring of contextual cues. Children's ability to prioritise cues consistently increases with age (Chevalier, Dauvier, & Blaye, 2018). Children also perform better after practicing cue identification (Chevalier et al., 2014; Kray et al., 2013), when cues are easier to process (Chevalier & Blaye, 2009; Towse et al., 2007) or when they are explicitly reminded of the relevant goal (Barker & Munakata, 2015b). However, the goal-identification framework does not speak to how goal identification is achieved when no external contextual cues are available.

As there is no external support to drive what to do and when to do it in self-directed control, goal identification in this form of control relies on processes other than cue processing. For instance, in the Verbal Fluency, reducing the high goal identification demands (i.e., choices between multiple competing sub-categories) by activating abstract representations through contextual reminders provided before the task (e.g., ‘a lion is a zoo animal’), therefore allowing an easier identification of the different main sub-categories, enhances performance in children younger than 7-years-old as evidenced by higher switching scores (Snyder & Munakata, 2010, 2013). These results suggest that abstract representations may play an important role in self-directed goal identification.

Since Vygotsky (1978), abstract representations have often been conceptualized as critical in higher cognitive processes such as cognitive control. For instance, an influential theoretical account on externally driven control development, the Iterative Reprocessing (IR) model (Cunningham & Zelazo, 2007; Zelazo, 2015; Zelazo & Cunningham, 2007), which builds on the Levels of Consciousness (LOC; Zelazo, 2004) and the Cognitive Complexity and Control theory Revised (CCC-r; Zelazo et al., 2003), states that age-related gains in cognitive control skills (cognitive flexibility, working memory, inhibition; Miyake et al., 2000) are driven by growing reflection. Within this framework, reflection is defined as the goal-directed elaborative reprocessing of information, which allows for the construction of more complex (and therefore more abstract) representations or formulation of more complex rules that can be used to control behavior more efficiently. The process of reflection occurs when children stop the ongoing stream of consciousness or action to consider their own skills or knowledge for a given situation to apprehend more complex rules. As reflection involves the reinterpretation of one’s own representation (i.e., taking a psychological distance with the goal-directed problem at hand), it is intrinsically metacognitive in nature.

Nevertheless, the IR model tells us little about how abstract representations are increasingly and more adaptively used autonomously with age. Rather than conceptualizing the development of cognitive control towards more autonomy through the maintenance of increasingly abstract representations, Doebel (2020) argued that children develop skills in engaging cognitive control strategically to serve specific goals that activate and are influenced by diverse mental states such as knowledge, beliefs, and values. Therefore, progress in cognitive control, in this respect, is thought to be driven by the acquisition of these constructs and this provides a better explanation of how goals may be identified in an increasingly self-directed fashion. For instance, if a child witnesses a peer stealing their toy, without knowing what it feels like to get hit or believing that anyone would be reprimanded for engaging in hitting, then this child would need explicit prompts from an adult to not hit their peer. Indeed, with the use of this knowledge and belief, children engage increasingly cognitive control autonomously to find alternatives (e.g., discussions with the peer, seeking an adult intervention) to identify and achieve the specific goal of retrieving the toys.

Thus, based on these models, we argue that children become better at identifying goals in a more self-directed fashion, possibly thanks to greater reflective and/or abstract representation abilities, as well as better knowledge, beliefs and values that serve these goals. However, the question of the exact cognitive mechanisms underlying goal identification when no environmental aids are available remains open.

Context-tracking and goal selection

If the specificity of self-directed control relates to the way goals are identified and goal identification progress drives age-related change, then the next challenge is to determine which exact processes underpin self-directed goal identification and how they develop during childhood. We propose that goals are self-directedly identified through accumulated knowledge (Doebel, 2020) which guides how children keep track of the different sub-goals and goals, before their selection and execution. Indeed, as children gained knowledge from the contextual information in their environment such as in less-structured activities, this predicts better performance in self-directed control (Barker et al., 2014) and externally driven control (Stucke et al., 2022).

More specifically, we argue that self-directed goal identification requires keeping track of contextual information, which we refer to as *context tracking* (i.e., monitoring, activating, and maintaining). The nature of this contextual information differs from the tangible contextual cues that directly signal what to do in an externally driven fashion (e.g., a glare from the parent or verbal instructions for the need to clean up one's room). Instead, we suggest self-directed control hinges mostly on contextual information related to past and future events and actions, that is, what has already happened or been done and what will or should happen in the future. For instance, if a teenager has played video games all afternoon and has a school exam the next day (context), they may self-directedly decide to study after dinner (as opposed to being told to do so by their parents in an externally driven fashion). Thus, contextual information is influenced by past actions and the foresight of future ones. In the Verbal Fluency task, for instance, children must keep track of the categories they have already used (e.g., farm animals) to decide when to switch categories and which one to switch to (e.g., zoo animals). Similarly, in the Voluntary Task Switching (VTS) paradigm (Arrington & Logan, 2004; Frick et al., 2019), where children can freely decide which game to play on a trial-by-trial basis but have to play each game equally often and in a random order, they need to keep track of the tasks they have already performed to decide which one to perform next. Further, as attainment of a specific goal (e.g., prepare dinner) may require a series of sub-goals (e.g., cut ingredients, boil water, etc.), the ability to keep track of the context or context-tracking likely involves information about where one stands in a hierarchy of sub-goals and goals. More generally, self-directed control development may relate to children's growing ability to navigate time, keeping track of the past and projecting oneself into the future, and thus to both long-term memory and prospective memory.

Keeping track of contextual information is essential but not sufficient. Individuals must also use this contextual information to determine when and what behaviour and how this behaviour should be engaged in order to achieve sub-goals and goals, which we refer to as the ability to select goals or *goal selection*. Goal selection is common to self-directed and externally driven forms of control engagement. It may correspond to the task goal activation process ("what to do") and the task rule activation ("how to do it"; De Baene et al., 2012), where the former has largely been shown to be influenced by the variations in the context (De Baene & Brass, 2014). We argue that the relation between context-tracking and goal selection is bi-directional. Indeed, although context-tracking guides goal selection by providing information about sub-goals and goals, goal selection may also influence the content of this information, as this information must be updated after a task has been selected so that one can move on to the next relevant task (i.e., once a task has been selected, this selection should be considered when one keeps track of the context; see Figure 1).

Goal selection likely involves metacognitive and reflective abilities acting on context-tracking, as one must reflect on the sub-goals and goals just selected and how this influences the hierarchy between goals within context-tracking. A link can be made here with the LOC model (Zelazo et al., 2007), where one major developmental milestone in cognitive control development occurring around the age of 5-years-old is the ability to take into account how different perspectives are related (e.g., how the same card can be sorted according to one dimension (color) and then another (shape)). According to the LOC model, this developmental milestone is reached when children achieve a level of consciousness (reflective consciousness 2 or refC2) which allows the formulation of higher rule representations that incorporate two incompatible past and present self-perspectives. As such, this level of consciousness allows children to navigate time by keeping track of the history of the self and the history of the world. This reflection-elicited time awareness might be critical for context-tracking.

Equally important, we argue that context-tracking allows one to store and update where they stand in the hierarchy of goals and sub-goals. Critically, the number of goals and sub-goals that can be stored and updated likely varies with increasing working memory with age. This echoes the *M* capacity, which is at the heart of working memory functioning and corresponds to a limited domain-general attentional resource for activating task or goal-relevant schemes (Pascual-Leone, 1970, 1987) and increases during childhood (see Case, 1985). We therefore hypothesize that gains in the ability to efficiently use context-tracking are more strongly related to working memory capacity increase than goal selection is.

Finally, context tracking feeds into goal selection which, in turn, guides how tasks are implemented through the *goal execution* process. We believe that the executive processes involved in goal execution are identical regardless of the extent to which control is engaged self-directedly or in an externally driven fashion. More specifically, goal execution processes likely include the three main components of the unity and diversity model of cognitive control (Miyake et al., 2000): inhibition, working memory updating, and set shifting, although other processes such as selective attention are probably also at play. In contrast, context-tracking and goal selection may correspond to, and help clarify, the nature of the Common EF component of the revised unity and diversity model (Miyake & Friedman, 2012). Indeed, that model's authors suggested that goal identification may be key to Common EF (Friedman & Miyake, 2017). Importantly, however, goal execution is likely to have a strong impact on the environment it is acting on. Therefore, goal execution also impacts on contextual information, which might lead to a change or a revision in goal identification if, for example, an error occurs (see Figure 1).

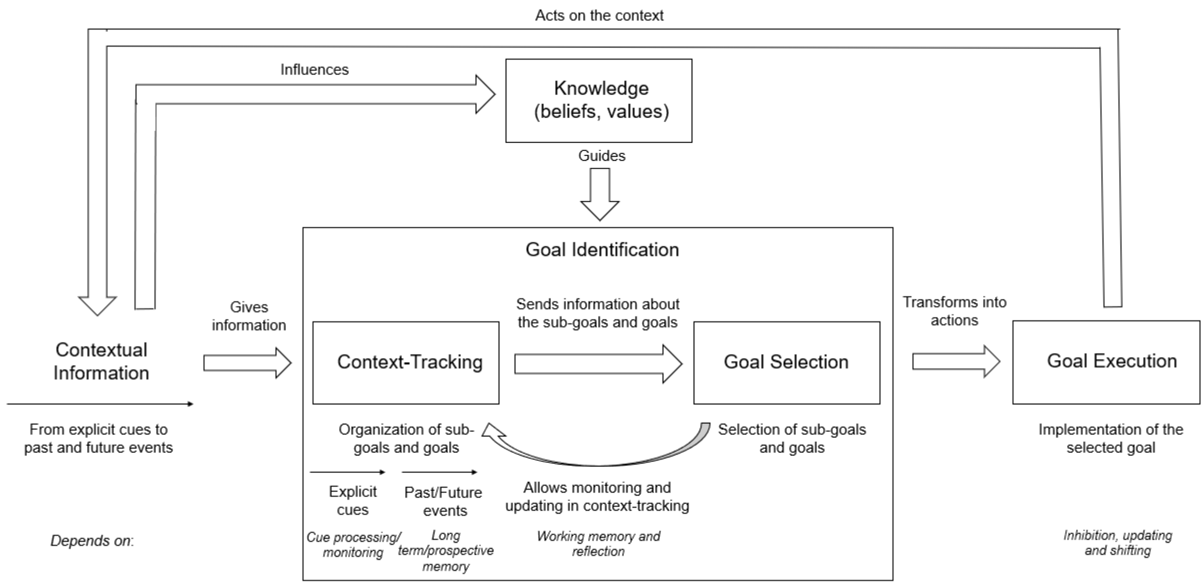

Figure 1. Representation of the underlying processes of goal identification in self-directed control engagement and its development with age. An example to illustrate this model could be preparing a homemade gift for a parent's birthday. The relevant information from the context is the date of the birthday. With age and increasingly better knowledge, the child becomes better at identifying the goal of preparing one specific homemade gift without external prompts from the other parent. Once the goal is identified, there are several sub-goals that are hierarchically organized in the context-tracking process that allows the child to keep track of where they currently stand in the hierarchy of the sub-goals (e.g., gathering materials, crafting, writing the note, wrapping the gift, hiding the gift). Then one of these sub-goals is then selected and implemented into actions by the goal execution process. Once the sub-goal is selected, the context-tracking process manipulates and updates the organization of the other sub-goals to, for instance, place crafting as the next sub-goal after gathering the materials. Nevertheless, the action that fulfils the goal of gathering the materials retroactively influences the contextual information. For instance, if one material is no available this might lead the child to revise the current goal or identify another goal for crafting.

Key predictions

1. *Context-tracking is responsible for more developmental progress than goal selection*

The model leads to the specific prediction that developmental progress in self-directed control will be mostly driven by greater context-tracking efficiency with age. This is because self-directed demands directly influence the difficulty of context tracking, whereas goal selection and execution should operate largely in the same way regardless of self-directedness demands. Indeed, the demands on context-tracking are higher when there is less environmental information available and when this process relies more heavily on personal memory than cue processing or monitoring. Two recent experiments using the VTS varied the difficulty of each process by providing or not providing contextual support that facilitated context-tracking (Study 1) and by manipulating task difficulty (a)symmetry to make goal selection easier or harder (Study 2; Frick et al., 2022). In these versions of the VTS, children had to choose which task to perform between a color and a shape task (e.g., sorting a bidimensional stimulus according to its color or shape) with child-friendly instructions matching the instructions to perform each task equally often and randomly used with adults. Importantly, these authors considered two indices: task balance (i.e., how well children performed the two tasks equally often) and task unpredictability (i.e., how well children performed the two tasks randomly). Not providing contextual support negatively affected task balance, but did not affect task unpredictability, as compared to providing contextual support. Moreover, when the task difficulty was asymmetric (making goal selection harder), task balance was positively affected whereas task unpredictability was negatively affected. These results suggest that task balance is mostly sensitive to context-tracking whereas task unpredictability mostly captures goal selection, and that context-tracking and goal selection are separable processes. Most importantly, varying the difficulty of context-tracking yielded a greater benefit in younger participants, whereas the goal selection difficulty similarly affected all age groups. Critically, younger participants are aged between 5- and 6-years-old which correspond to the ages that have been identified to be critical for working memory development (Case, 1985) and reflection abilities (Zelazo, 2015; Zelazo et al., 2007; see previous Section). Although both context-tracking and goal selection contribute to successful self-directed control engagement, developmental progress seems to be mostly driven by context-tracking rather than goal selection *per se*, although this will need to be confirmed in future studies.

2. Goal execution is separable from goal selection

In our model, a task must be selected before it can be executed. Therefore, these stages are dissociated. Experimentally, these two processes can be dissociated within a simple manipulation such as in the double registration procedure (Arrington & Logan, 2005) where participants first select the task they want to perform (goal selection) before performing the selected task (e.g., by pressing the blue key to respond to a blue-teddy-bear if they have selected the colour game). In a study using the double registration procedure, children reached adult-like performance for goal selection later than for goal execution, indicating that the latter process may be easier than the former, but more importantly that these two processes are somehow independent (Frick et al., 2021). More surprisingly, although one may assume that self-directedness affects goal selection but not goal execution, the same study also revealed greater performance costs both for goal selection and goal execution when self-directedness demands increased, potentially indicating that the difficulty of goal selection transfers to goal execution. Contextual cues (low self-directedness demands) may support not only goal identification but also goal maintenance, hence providing clearer top-down guidance on information processing and response selection, relative to situations with high self-directedness demands.

3. *Context tracking relates to working memory, long-term memory, and prospective memory*

As context tracking involves monitoring and maintaining contextual information, we argue that it relates to working memory from a theoretical viewpoint (Pascual-Leone, 1970; Case, 1985). In addition, there is also empirical evidence supporting that working memory is related to self-directed tasks. For instance, in the Verbal Fluency task, adults with greater working memory capacity typically produce a higher number of words and commit fewer preservative errors than adults with lower working memory (e.g., Amunts et al., 2020), and these findings have recently been extended to children (Filippi et al., 2022). Working memory may support maintenance and updating of previously selected words, hence facilitating context-tracking. However, it is unknown whether and how working memory may underlie more subtle components of the Verbal Fluency performance such as the size of clusters of words or the number of switches between clusters, which are finer-grained measures of the self-directedness (Saranpää et al., 2022). Similarly, performance at the WCST in children has been linked with working memory performance (Mullane & Corkum, 2007) and it has been shown that increasing the number of card-sorting rules in this task, therefore increasing the working memory load from the context, causes impaired performance in individuals which reduced working memory capacity (Lange et al., 2016). This study provides suggestive empirical evidence that working memory capacity would be key to context-tracking, but more studies are needed to better capture how working memory contribute to context-tracking.

Perhaps more specific to the present model is the prediction that the relations of cognitive control to both long-term memory and prospective memory should be explained mostly by context-tracking (and goal selection) rather than goal execution. Thus, correlations between cognitive control performance and both long-term and prospective memory performance should increase in magnitude with self-directedness demands. We predict such a link with long-term memory because of the need to keep track (or reactive in working memory) of past events and actions. Indeed, the Experience-Driven Maturation model of cognitive control (Murty et al., 2016) also hypothesises a close relation between long-term memory and cognitive control. Specifically, according to this model, increasing connectivity between the prefrontal cortex and the hippocampus with age supports more reliable incorporation of information from past experiences to better guide top-down control of attention and actions in new situations that share features with previous experiences so that one can better identify goals and subsequent actions are most likely to be successful. Similarly, age-related increase in prefrontal cortex-hippocampus integration may drive gains in context tracking in situations where control must be engaged in a self-directed fashion.

As contextual information also includes future events, integration of contextual information related to past events/actions must often be integrated with future events, which need to be anticipated. As such, context tracking may be closely related to prospective memory, that is, the ability to remember to perform a specific action (e.g., buy bread) either when an event occurs (e.g., when walking by the bakery after work) or after a certain delay (e.g., before the bakery closes) without external guidance (Zuber et al., 2019). Indeed, prospective memory and cognitive control are closely related during childhood and the development of the prospective memory has been argued to build on control progress with age (e.g., Mahy et al., 2014; Zuber et al., 2019). The relation may well be bidirectional with prospective memory progress contributing to greater self-directed control with age too. Interestingly, prospective memory has also been hypothesised to relate to proactive control (Mahy & Munakata, 2015), which consists in engaging control in anticipation of future events in order to minimize the interference they could otherwise engender (Braver, 2012). Like self-directed control, proactive control matures relatively late in childhood and involves consideration of future events or actions; thus, an open question for future research is whether the two forms of control (and their respective developmental courses) may be related to each other.

Other research directions

Our present model offers several promising venues for future research. To begin with, one remaining important ability that might play a critical role in self-directed control development is metacognition, as reflective abilities may be necessary after a goal or a task is selected to navigate in increasingly complex and abstract representations (as postulated by the IR/LOC models; Zelazo, 2015). Indeed, metacognitive abilities coupled with knowledge may help children decide without external guidance when to pursue a specific goal and how to engage control toward it in order to maximize their performance to maximize. For instance, the metacognitive knowledge that one works better when they are not tired may help children self-directedly decide when to study for a school exam (i.e., avoiding studying late at night) to maximise reward (likelihood to pass the exam). Indeed, a growing body of research has shown that cognitive control development is supported by metacognitive gains (e.g., Chevalier, 2015a; Chevalier et al., 2015; Niebaum et al., 2019; O'Leary & Sloutsky, 2019; Roebers, 2017), although future research is needed to explore whether metacognitive gains support self-directed control development specifically.

Another important future direction will consist in investigating how motivation, mood or fatigue might play a role in how children engage self-directed control. Critically, there is behavioural and neural evidence that cognitive control skills vary on a continuum from cold cognitive control to hot cognitive control (also referred to as cold and hot executive function; Zelazo & Müller, 2002). Cool cognitive control refers to skills assessed in emotionally neutral tasks or activities and involves more lateral part of the prefrontal cortex whereas hot cognitive control is needed in situations where motivation is relevant and relies more on ventral and medial part of the prefrontal cortex (for a behavioural and neural distinction between cold and hot cognitive control, see Moriguchi, 2022). Of particular importance, most theoretical models of cognitive control such as the unity-and-diversity model (e.g., Miyake et al., 2000), focus on cool cognitive control tasks that use non-emotional stimuli (e.g., Stroop task, n-back task). The studies reviewed account for a model of cold self-directed control development. However, motivation, mood and fatigue are likely to play a critical role in the development of this form of cognitive control. For instance, based on the Self-Determination Theory (Ryan & Deci, 2000), which states that autonomy is one of the basic needs that motivate humans, Grolnick and Raftery-Helmer (2013) argued that autonomous self-regulation is driven by increasingly intrinsic motivation that is enhanced if parents provide adequate support (e.g., support their initiations, involve them in problem solving decision, taking their perspectives). Future accounts of self-directed control development should investigate the role played by motivational issues in how children engage this form of control.

In the same vein, there are several points that remained to be addressed by our model in order to provide a better account of self-directed control development. Indeed, we argue that context-tracking is responsible for most age-related progress in self-directed control, as compared to goal selection. Although, there seems to be suggestive evidence for this claim, further experimental works dissociating these two processes in the development are needed. Relatedly, according to our model, context-tracking and goal selection are dissociated but related processes. However, it is unclear whether one of these processes develops in separating from the other process (e.g., tracking out of selection). A last point not explained by the current version of the model is how conflict detection is achieved. We believe that this this should be treated when context-tracking monitor the goals and sub-goals. If so, this would suggest that this process may involve one or several sub-processes that future work should clarify.

Finally, to answer all these remaining questions to better capture the function of context-tracking and goal selection as well as the role played by other cognitive components in self-directed control development, we need to develop new experimental tasks tapping in this form of control. Indeed, only a handful of tasks are currently available in the literature such as the Verbal Fluency, WCST and VTS. This is mainly because designing self-directed tasks suitable for use with children is particularly challenging, as these tasks often involve complex instructions. However, the VTS, which has recently been used and adapted for use with young children (de Bruin et al., 2020; Frick et al., 2019) seems a promising paradigm for future research as it allows for many experimental manipulations that can be useful for further testing the present theoretical model.

Conclusion

To conclude, we propose here the first tentative theoretical account of the underlying cognitive processes of self-directed control and its development across childhood. This form of control is largely under-researched in the developmental literature, despite its offerings in helping us to better understand how cognitive control contributes to the development of autonomy in childhood and more important how it underlies academic achievement. Moreover, self-directed control and its underlying cognitive processes, and more particularly context-tracking, is likely to be linked with several cognitive abilities such as working memory, prospective memory and metacognition. As such, better understanding how all these processes and abilities work together might inform us about the more general mutual relations between cognitive control and these other critical cognitive abilities.

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