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The development of learning, performing, and controlling repeated sequential actions in young children

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Abstract

Our daily lives are composed of several sequential actions that we perform routinely, such as making breakfast, taking a train, and changing clothes. Previous research has demonstrated that a routine system plays a role in performing and controlling repeated sequential actions in familiar situations, and a top-down control system involves the control of the routine system in novel situations. Specifically, most developmental studies have focused on the top-down control system (e.g., executive functions) as a factor enabling the control of goal-directed actions in novel situations. Yet, it has not been thoroughly examined how young children learn, perform, and control repeated sequential actions in familiar contexts. In this review, based on recent computational accounts for adults, we highlight two critical aspects of the routine system from a developmental perspective: (1) automatic flexible changes of contextual representations, which enables humans to select context-dependent actions appropriately; and (2) detection of deviant situations, which signals the need for control to avoid errors. In addition, we propose the developmental mechanism underlying the routine system and its potential driving factors such as statistical regularities and executive functions. Finally, we suggest that an investigation into the interplay between routine and executive functions can form foundations for understanding learning, performing, and controlling repeated sequential actions in young children and discuss future directions in this area.

Keywords

routines, executive functions, young children, goal, context, graded representation

1. INTRODUCTION

In everyday life, we implement sequential actions in a goal-directed manner, such as making a cup of coffee, assembling furniture, taking a bus, and eating out at a restaurant. These sequential actions are repeatedly performed many times in particular contexts and come to involve highly practiced performance toward goals. We call these acquired action sequences *routines* in this article. Although routines normally operate without control demands in their acquired context, some control actions are required in the execution of routines in situations that deviate from the original sequences or contexts. Learning, performing, and controlling routines all influence each other, and these processes are the underlying basis of our everyday activities. It is well established that young children start to develop the ability to learn routines and control their own behavior from early childhood (e.g., Diamond, 2013; Fivush, 1984). In this article we primarily focus on how young children learn, perform, and control repeated sequential actions.

In the fields of cognitive science and neuroscience, researchers such as Norman and Shallice (1986) have examined the performance and control of sequential actions. According to their "dual system theory," there is a routine system—contention scheduling—that plays a role in performing and controlling repeated sequential actions in familiar situations, and a top-down control system—a supervisory system—that involves the control of the routine system in novel situations. Recently, Cooper et al. (2014) developed a computational model (i.e., "goal circuit model") about the relations between

the routine system and the top-down control system conceptually proposed by Norman and Shallice (1986). In this theoretical framework, it is critical that the two systems work together to learn routines as well as control them. Note that the core difference between the two systems is in the status of goal representations. The routine system allows individuals to perform sequential actions without actively maintaining goal representations, rather based on implicit contextual representations, whereas the top-down control system involves controlling sequential actions with reliance on the boosted activation and maintenance of goal representations.

In the field of developmental psychology, a great deal of research has focused on the early development of executive functions - the processes involved in the conscious control of goal-directed behaviors - to clarify the mechanisms and roles of the top-down control system in novel situations (e.g., Diamond, 2013; Garon, Bryson, & Smith, 2008; Munakata, Snyder, & Chatham, 2012; Zelazo et al., 2013). Although it is also well known that young children engage in a variety of routines such as going to school, building a house out of wood blocks, and bedtime reading (e.g., Nelson, 1981; Fivush, 1984) and sometimes encounter deviations from routines (e.g., Hudson, 1988), it has not been scrutinized how children learn, perform, and control sequential actions in familiar situations. Indeed, routines originate as goal-directed behaviors and, as mentioned earlier, may need to be controlled to attain goals in some situations (Galla & Duckworth, 2015; Kruglanski & Szumowska, 2020; Wood & Neal, 2007). Therefore, it

should be considered how the routine system develops, to elucidate the developmental mechanism underlying learning, performing, and controlling everyday activities.

We review recent studies concerning repeated sequential actions in young children and highlight two critical aspects of the routine system. First, we highlight flexible changes of contextual representations as a mechanism of learning and performing routines. Next, we focus on detection of conflicts with hierarchical goal representations as a mechanism of performing and controlling routines. We also confirm the relevance of recent empirical evidence and computational models concerning adults. Thereafter, we propose the potential developmental mechanisms underlying the routine system in young children and clarify two factors that influence developmental changes in the routine system: statistical information and executive functions. Finally, we summarize theoretical and practical contributions of this review and suggest possible future directions.

2. DEVELOPMENTAL EVIDENCE ON THE ROUTINE SYSTEM

2.1. Flexible changes of contextual representations

Routines formed in early childhood are useful for children to forecast what will happen in novel situations as well as to promote planning, pretend play, and communication (e.g., Furman & Walden, 1990; Seidman, Nelson, & Gruendel, 1986). It has been well established that the repeated experience of performing sequential actions in everyday life or in a laboratory leads to learning routines from early childhood. For example, not only 3-year-olds but also toddlers can accurately imitate sequential actions

they perform routinely (e.g., taking a bath, making a sandwich) or watch several times in an experimental setting (e.g., Bauer & Hertsgaard, 1993; Bauer & Mandler, 1992; Loucks, Mutschler, & Meltzoff, 2017; Loucks & Price, 2019; Whiten, Flynn, Brown, & Lee, 2006). Furthermore, preschoolers are able to accurately perform repeated sequential actions without explicitly being instructed how to perform them (Hudson & Fivush, 1991; Hudson, Shapiro, & Sosa, 1995; Yanaoka & Saito, 2017). Although previous studies examined such competence in children, it has been neglected how children learn to perform routines.

According to empirical evidence and computational models concerning adults, learning and performing routines is driven by consecutively predicting a next step based on implicit contextual information regarding what has been seen and done previously and what goals have been active (e.g., Botvinick & Plaut, 2002, 2004; Cooper et al., 2014; Lashley, 1951). Botvinick and Plaut (2002) proposed an influential account of the routine system, in which the contextual representations underlying routines flexibly change based on whether the representations are relevant to a particular action. They provided an example of making tea or coffee. The processes of making tea or coffee have several actions in common such as boiling water and preparing a cup; however, there are also unique actions that rely on contextual information (e.g., adding sugar to coffee but not necessarily to tea). The transition from one subsequence to the context-dependent action is less coherent and susceptible to errors (Arnold, Wing, & Rotshtein, 2017; Reason, 1990; Ruh, Cooper, & Mareschal, 2010). Therefore, when sequential actions are learned

as routines, the contextual information becomes represented more distinctively at this transition point. In contrast, selecting common actions between making tea and coffee does not rely on the contextual information about which goals have been active (e.g., making tea or coffee); thus, the contextual representations become represented more vaguely during the performance of the common actions as sequential actions become more routinized.

It has also been argued that the flexible changes of contextual representations are reflected in the susceptibility to the interruptions during performing routines. Specifically, Botvinick and Bylsma (2002, 2004) assumed that individuals are less susceptible to interruption at the point when contextual representations are distinctively represented as compared with when they are vaguely represented. Botvinick and Bylsma (2005) empirically tested this assumption by requiring participants to repeatedly make a cup of coffee and implementing a short interruption task during making coffee. They evaluated the frequency of action slips (e.g., reaching toward the sugar canister when sugar had already been added) in conditions in which interruptions were inserted just before context-dependent actions (e.g., when completing adding milk and stirring) or at the middle of subtasks before context-dependent actions (e.g., while pouring milk into the cup). They demonstrated that inserting the interrupting task at the middle of subtasks generated more action slips than just before the context-dependent action, suggesting that contextual representations become attenuated at the middle of the subtask sequences but recover at the end of the subtask.

To examine whether routines that children learn are supported by the flexible representations of task context, Yanaoka and Saito (2019) developed a routine acquisition task for young children. In this task, children were required to play the role of a baker and make toast for either a cat or a mouse that visited the bakery as a customer. An important characteristic of this task is that the children were asked to make toast repeatedly—following one recipe for a cat and another recipe for a mouse. Interrupting tasks were inserted while the toast was being made. Based on Botvinick and Bylsma (2005), the timing of the insertion of interrupting tasks was divided into either after the completion of the behavior that immediately preceded the branching of whether to use a cat or a mouse recipe (completion interruption), or while the behavior that immediately preceded the branch point was performed (intermediate interruption). The results indicated that five-year-olds tended to be more affected by the intermediate interruption than the completion interruption, in comparison with four-year-olds. Yanaoka and Saito (2021) replicated a similar developmental pattern among three- to six-year-olds. These findings suggest that older children learn routines more efficiently and their performance of sequential actions is supported by the flexible changes of contextual representations, which enables them to select context-dependent actions automatically.

2.2. Detection of conflict with goals

When individuals encounter non-routine situations, they need to control the execution of routines. In such situations, the top-down control system, proposed by Norman and Shallice (1986), plays a primary role in activating goal representations,

selectively biasing context-driven action schemas in the routine system, and generating appropriate sequential actions toward goals. Here, what is more important is that the routine system triggers the activation of the top-down control system if necessary. One mechanism for triggering the need for control is prediction. During the performance of routines, individuals can automatically predict the next basic actions, subgoals, and superordinate goals on the basis of implicit contextual information (Botvinick & Plaut, 2004; Cooper et al., 2014). Cooper (2019) suggested that the automatic predictions enable us to monitor the difference between actual goals stored in the top-down control system and the predicted consequences derived from current situations and make it easier to notice the situations that will result in deviations from the goals. The detection of such situations signals the need for proactive control and activates the top-down control system, which modulates the routine system and resolves conflicts toward goals (see Figure 1). Although the operation of the routine system is automatic, it involves triggering top-down control as needed through automatic predictions and indirectly contributes to control repeated sequential actions.

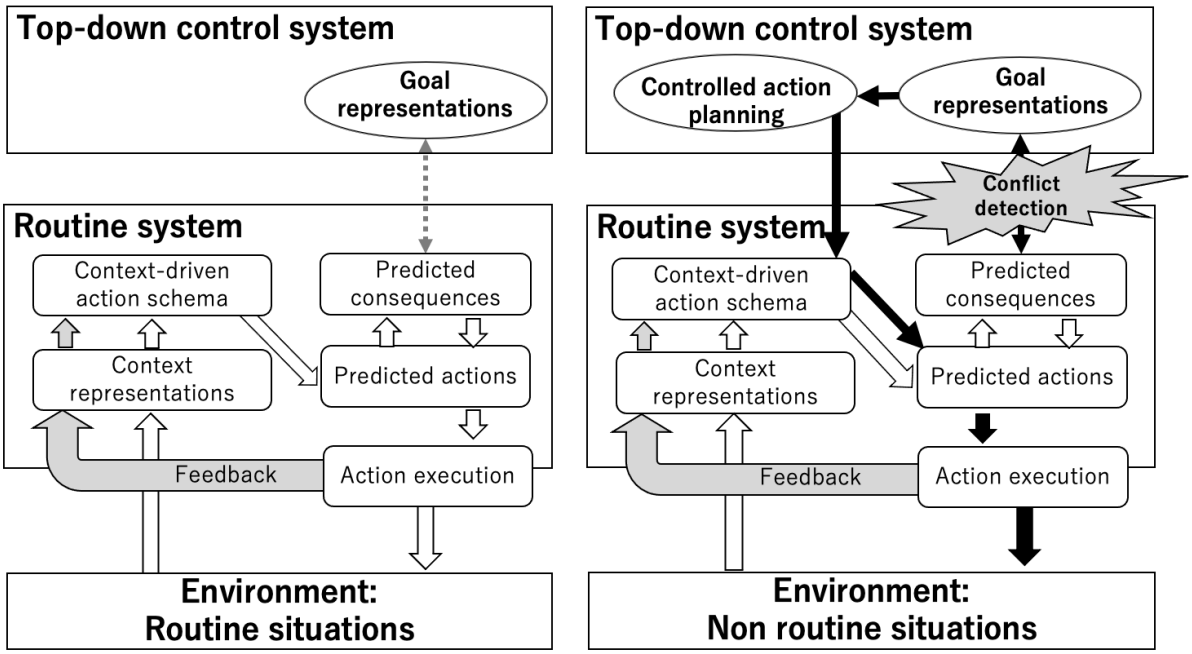

Figure 1. The conceptual framework for learning, performing, and controlling repeated sequential actions. White arrows depict automatic processes by the routine system, whereas black arrows depict intentional processes by the top-down control system. In the routine situation (left-sided), implicit contextual representations based on prior states activate context-driven action schemas, meaning that individuals can automatically generate predicted actions and their consequences. The execution of the predicted actions is fed back to implicit context representations, leading to the promotion of learning routines. In the non routine situation (right-sided), the predicted consequences mismatch with goal representations stored in the top-down control system, signaling the need for proactive control and triggering the top-down control system. This is accompanied by the boosted activation of goal representations, which helps individuals to plan controlled actions, selectively bias context-driven action schemas, and execute appropriate actions to resolve conflicts toward the goals. The execution of the controlled actions is also fed back to implicit context representations, thereby the context representations can be updated. Note that goal representations in this figure are depicted as a single entity, but they have a hierarchical structure in reality.

There is some developmental evidence on the role of the routine system in triggering the need for control, suggesting that young children gradually develop a routine system that helps them detect conflicts with a goal (Freier, Cooper, & Mareschal, 2015; Loucks & Meltzoff, 2013; Yanaoka & Saito, 2017). For instance, Freier et al. (2015) demonstrated that three- and five-year-olds can imitate familiar sequential actions

accurately (i.e., preparing a sandwich); however, when observing a misleading demonstration that included goal-irrelevant actions (e.g., taking a bag of sugar out of a transparent glass jar), three-year-olds tended to engage in overimitating the irrelevant actions while five-year-olds avoided the overimitation. This finding suggests that the routine system in both age groups works well to imitate familiar sequential actions; however, the more developed routine system of five-year-olds may have reinforced the detection of the conflict between irrelevant actions and the overarching goal of the observed sequence.

Furthermore, when 3-year-olds observed an adult demonstrate sequences in which actions related to one goal (e.g., taking a bath) are interrupted by actions related to a second distinct goal (e.g., preparing for bedtime), they avoided overimitation by spontaneously grouping actions according to each goal (Loucks & Meltzoff, 2013). This finding also suggests that even 3-year-olds can detect conflicts with a current goal based on the operation of their routine system and reorganize sequential actions according to each distinct goal.

Yanaoka and Saito (2017) further highlighted the main goal/subgoal structure of routines. They used a doll task (Yanaoka, 2014), which was developed to measure the ability to perform routines for changing clothes. In this task, children were asked to help a doll put on seven items (shoes, shirt, blazer, trousers, socks, underpants, and school bag) to attend kindergarten. Four- and five-year-olds could help a doll change clothes without any errors. They also judged whether they should put on the items from each shelf of the

closet one-by-one and encountered order errors of the items from invariant order categories (e.g., trousers appearing before underpants). In this condition, five-year-olds noticed and proactively corrected deviations from the invariant order more so than four-year-olds did. This suggests that the routine system of five-year-olds helps them to detect the conflict with either the main goal (i.e., changing clothes to attend kindergarten) or the subgoals (i.e., putting on the next appropriate items). In their study, the order of items in the variant order category is also critical, such as donning either a blazer or trousers after putting on a shirt and underpants. The order of these items (e.g., a blazer or trousers) is inherently changeable. Here, Yanaoka and Saito (2017) assumed that, when children expect a particular item to be on the next shelf, this expectation could be a subgoal of the next action. If children encounter an unexpected item that conflicts with the subgoal, they might activate the top-down control system based on the subgoal and unnecessarily skip the item and move to the next shelf even when the item is from the variant order category. In contrast, if children predict several potential items for attaining the main goal, children might avoid skipping the items from the variant order category unnecessarily to help the doll attend kindergarten. Thus, they would activate the top-down control only when they detect conflicts with the main goal. The results showed that, among the children who could correct the wrong order of the invariant order items, older children were more likely to accept any order of the variant order items; but younger children unnecessarily corrected the variant order items. It was suggested that the detection of conflicts by the routine system develops from mainly relying on the subgoals to the main goal in the

hierarchical goal representations and leads to the resolution of the conflicts by the top-down control system.

Taken together, the routine system contributes to signaling the need for control through access to hierarchical goal representations, leading to the control of repeated sequential actions by the top-down control system. Given that conflict detection is assumed to be accomplished by the interaction between the routine system and hierarchical goal representations stored in the top-down control system, it is possible that development in both of these component systems contributes to the detection of conflicts with goals during the performance of routines.

3. WHAT SUPPORTS DEVELOPMENTAL CHANGES IN THE ROUTINE SYSTEM?

3.1. Developmental mechanisms

We have so far introduced findings about how young children engage in learning, performing, and controlling repeated sequential actions. In this section, we discuss a potential developmental mechanism underlying the routine system. One promising mechanism can be provided by the graded representation account (Munakata, 2001), which argues that representations can be graded, rather than simply being present or absent, in terms of how "clean" they are for conveying appropriate information as opposed to being corrupted by noise or damage. Weak (i.e., noisy) representations may be sufficient for tasks not involving conflicts, whereas strong (i.e., clean) representations are required to solve problems in the face of conflicting information (Ganea & Saylor, 2013;

Jordan & Morton, 2012; Morton & Munakata, 2002; Munakata, 2001). Thus, individuals who have weak representations are likely to exhibit behavioral dissociations and preservative errors. For example, in the Dimensional Change Card Sort (DCCS) task, children who have weak representations can answer a verbal question about the new rule, not involving conflicts (e.g., Where do "red things" go in the color game?), but incorrectly sort conflict cards under the newly switched rule (e.g., although children were asked to sort "a red star card" in the color game, they put it into the box that "a blue star card" is attached according to a previous relevant shape rule; Zelazo, Frye, & Rapus, 1996). As another example, in the A-not-B task, infants who have weak representations can gaze correctly at a new location where they have watched a toy being hidden, but incorrectly reach back to an old location where the toy was previously hidden (Munakata, 1998). In both examples, strong representations are required to reduce such behavioral dissociations and preservative errors.

Applying this account to the developmental findings about the routine system, we can assume that weak contextual representations underlying routines would lead to unclear predicted consequences, which are sufficient for performing repeated sequential actions smoothly but not for detecting conflicts with goals during the performance of repeated sequential actions. In contrast, strong contextual representations would lead to clear predicted consequences, which trigger the top-down control system and enable children to control repeated sequential actions in response to conflicts with goals. Consistent with this, previous studies (Freier et al., 2015; Yanaoka & Saito, 2017)

showed that younger children imitated or performed familiar sequential actions well; however, they failed to deal with conflicting information during the performance of repeated sequential actions, suggesting that they might not have acquired strong contextual representations underlying repeated sequential actions yet.

This graded representation account can also explain the developmental transformation in flexible changes of contextual representations. As mentioned earlier, older children, but not younger children, can learn contextual representations to be distinctive in selecting context-dependent actions as well as vague in selecting actions that do not rely on contextual information (Yanaoka & Saito, 2019, 2021). The dynamic and efficient modification of representations requires fine-grained characteristics of the representations. In other words, cleanness is a precondition of representations for flexible changes. Therefore, it is expected that older children who are assumed to obtain strong/clean representations will exhibit flexible changes of contextual representations whereas younger children who are assumed to hold weak/noisy representations will not.

It has been demonstrated that the strength of representations is associated with some developmental factors such as the amount of experience and the development of working memory capacity. For example, infants can gradually develop strong representations of objects though the experience or contacts with the objects, resulting in greater sensitivity to a hidden toy in the A-not-B task (Shinskey & Munakata, 2005). Furthermore, the strong rule representations, which lead to flexible switching in the DCCS task, rely on the maturation in the prefrontal cortex (Morton & Munakata, 2002)

and link to working memory development (Blackwell, Cepeda, & Munakata, 2009). Given the evidence, the amount of experience with performing routines and working memory development would partially explain developmental differences in the strength of contextual representations underlying the routine system.

3.2. Factors driving the developmental changes in the routine system

3.2.1. Statistical information

One critical factor that supports learning routines is statistical information. Routines are hierarchically structured; thus, they are decomposed into a series of subtasks, within which action steps are also included. Binding some action steps into a subtask partly depends on transitional probabilities of action steps. In a simple recurrent model by Botvinick and Plaut (2004), action steps that always appeared together in a particular order became represented as one subtask, while action steps that appeared in a variable order were learned to be represented as a part of different subtasks. This is true of sequential order information between subtasks. Taking again the example of making coffee, higher transitional probabilities of subtasks yielded invariant order (e.g., adding coffee grounds into a cup before adding milk), whereas lower transitional probabilities yielded variable order (e.g., adding milk and sugar). These findings suggest that statistical information underlies two important aspects of routines: a hierarchical structure and sequential order relations.

According to Botvinick and Plaut (2004), the acquisition of statistical regularities heavily depends on the amount of training and number of training sets; that is, how many

times we experience sequential actions and how valuable the experience that we gain is. This is evidenced by abundant findings about statistical learning, in which adults and infants can use statistical regularities in sequential actions as well as in linguistic input (e.g., Baldwin, Andersson, Saffran, & Meyer, 2008; Stahl, Romberg, Roseberry, Golinkoff, & Hirsh-Pasek (2014); for recent reviews, see Baldwin & Kosie, 2020; Levine, Buchbaum, Hirsh-Pasek, & Golinkoff, 2019; Saffran, 2020). For example, Baldwin et al. (2008) asked adults to watch a person performing continuous sequential actions in which certain action pairs occurred with high or low transitional probabilities. They found that adults can recognize action pairs grouped only by high transitional probabilities and can distinguish these pairs from other action pairs that never appear together or cross an action boundary. Stahl et al. (2014) applied a similar paradigm with seven- to nine-month-old infants, revealing that infants looked longer at action pairs that cross an action boundary than at high frequent action pairs.

In addition to action processing, preschoolers can use statistical information to selectively imitate only a subsequence that caused a particular outcome (Buchsbaum, Gopnik, Grifiths, & Shafto, 2011). In that study, children observed a sequence of three actions that caused a particular outcome several times (e.g., when the experimenter squeezes a toy, knocks on the toy, and pulls the toy's handle, the toy plays music), and then they were provided a chance to use the toy. There were two conditions, that is, conditions of "ABC" and "BC." In the "ABC" condition children saw only one sequence caused the effect three times (i.e., ABC, ABC, ABC), whereas in the "BC" condition

children saw three different sequences in which the first action was variable but the last two actions were fixed caused the effect (i.e., ABC, DBC, EBC). The result showed that children in the "ABC" condition imitated the complete sequence ABC more often than children in the "BC" condition, while children in the "BC" condition imitated the subsequence BC more often than children in the "ABC" condition. Taken together, these findings suggest that adults and children are both sensitive to statistical information embedded in sequential actions. Such statistical information can help children segment highly frequent subsequences and learn them efficiently.

Given that contextual representations underlie the routine system, it is possible that the statistical information would shape contextual representations. Performing a highly frequent subsequence requires only a context for the preceding action, whereas selecting a next action at a point with low transitional probabilities requires contextual information about a broader temporal or task context. Therefore, how contextual information is represented would partly depend on transitional probabilities of actions, suggesting that the routine system is partly relying on statistical information.

3.2.2. Executive functions

Another critical factor influencing the routine system is executive functions. More precisely, executive functions play a key role in learning goal-directed sequential actions as routines efficiently. This argument stems from the goal circuit model (Cooper et al., 2014), which updated the prior model (Botvinick & Plaut, 2004) by adding units of the top-down control system and hierarchical goal representations to the network. One

important characteristic of the goal circuit model is its goal-based learning, in which one learns what actions are selected to attain specific goals (e.g., drinking coffee), rather than learning how to follow a specific sequence (e.g., open a lid of a sugar bowl and then picking up a spoon). Specifically, when learning novel sequential actions, the model takes a representation of the current goal as an input and the goal representation is possibly modulated by the top-down control system and fed back into the model in the next processing step, leading to the generation of sequential actions toward the task goal. Another important characteristic of the goal circuit model is that the need for the top-down control system is reduced by learning or practice. With repetition of sequential actions toward a task goal, a contextual representation of task context is gradually accumulated in the model's internal hidden units. The contextual representation might change flexibly and allow the model to select the next appropriate action automatically, resulting in being less influenced by the top-down control system and learning sequential actions as routines.

Following the goal circuit model (Cooper et al., 2014), it can be expected that the development of the routine system would depend on individual differences in the top-down control system. In line with this prediction, the development of executive functions is related to the flexible changes of contextual representations while young children repeatedly perform sequential actions (Yanaoka & Saito, 2019). Furthermore, Yanaoka and Saito (2021) used the same toast making task as Yanaoka and Saito (2019) and examined the direct effects of executive functions on learning routines by inserting

reminders in the practice phase to prompt goal recall before their selecting a context-dependent action (e.g., the experimenter showed a picture of a mouse or a cat to the child and said “you are now making toast for a mouse (cat)”). The reminder was expected to reduce children’s cognitive demands on executive functions by helping them have access to goal representations in selecting context-dependent actions, and to promote the acquisition of routines. It was shown that reminders encouraged three-to six-year-olds to modulate flexible representations of task context during the performance of repeated sequential actions, indicating that reminders certainly promoted learning routines in young children. In other words, reminders reduce the demands of executive functions on performing sequential actions, and such a reduction in demands might partly contribute to young children’s abilities to learn routines. These findings suggest that the routine system partly depends on the development of executive functions.

Here the precise roles of executive functions in relation to routines must be identified. In this regard, considerations of the putative structure of executive functions might be useful. Executive functions are assumed to be composed of correlated but dissociable factors such as updating, inhibition, and shifting (Miyake et al. 2000). In addition, the active maintenance of goal representations has been shown to be the common constructs among these factors (Miyake & Friedman, 2012; Munakata et al., 2012). Each component may be uniquely related to learning, performing, and controlling sequential actions even in young children. For example, the above-mentioned studies (Yanaoka & Saito, 2019, 2021) consistently demonstrated that the representational

flexibility of contextual information is related to shifting abilities, measured by the advanced DCCS task (Chevalier & Blaye, 2009). Consistent with these patterns, Yanaoka and Saito (2021) reported that reminders support a subprocess of executive functions, i.e., having access to a task goal at a branch point, but do not perfectly compensate for the role of the shifting abilities in the representational flexibility of contextual information. Furthermore, a recent study showed that preschoolers' updating and inhibition abilities play different roles in planning sequential actions with Duplo blocks, demonstrating that updating is related to engaging in appropriate subgoals while inhibition is related to avoiding performing goal-irrelevant actions (Schröer, Cooper, & Mareschal, 2021). These findings highlight the usefulness of the component view of executive functions for the investigation into the routine system. Yet, we need to accumulate more pieces of evidence on this issue.

In relation to the graded representation account (Munakata, 2001), one can speculate on the relation between the strength/cleanness of explicit goal representations and the flexible changes of contextual representations. As discussed above, the development of the routine system can be explained by whether children can hold strong representations. Specifically, the ability to hold strong representations potentially presupposes the flexible changes of contextual representations. In the context of executive functions, there is growing evidence that the strength of explicit goal representations is critical to driving executive functions (e.g., Blackwell et al., 2009; Munakata et al., 2012; Munakata & Yerys, 2001). Considering that executive functions

contribute to the acquisition of routines (Cooper et al., 2014), it can be inferred that the strength of explicit goal representations would determine how flexible contextual representations are modulated during the performance of represented sequential actions. Although this view has not yet been confirmed, such an investigation might provide the opportunity to update the current goal circuit model from the viewpoint of graded representations.

4. IMPLICATIONS AND FUTURE DIRECTIONS

We reviewed recent developmental evidence of the routine system, revealing that flexible representations of a temporal or task context underlie the routine system in young children, and the development of the routine system enables children to detect conflict information based on hierarchical goal representations. It was also discussed that the development of the routine system can be explained by the graded representation account and subserved by a great deal of statistical information and the development of executive functions. The aforementioned evidence provides three theoretical and practical contributions to the understanding of everyday activities in young children.

First, the goal circuit model (Cooper et al., 2014) can fit well with the findings from children who start to develop executive functions. Following the goal circuit model, executive functions play a crucial role in selecting context-dependent actions through the process of activating and maintaining explicit goal representations, especially at the beginning of the learning phase. With repetition of performing sequential actions toward a task goal, performance comes to be routinized. This process is supported by flexible

changes of contextual representations. Furthermore, the acquisition of routines helps to trigger top-down control only when conflict information is detected. Thereby the involvement of executive functions in implementing repeated sequential actions is minimized. Therefore, there are complementary relations between the acquisition of routines and executive functions; that is, executive functions encourage the acquisition of routines and routines make us less reliant on executive functions except when they are needed. This view is true of the findings from three-to six-year-olds as well as adults. However, it remains unclear how the goal circuit model can be applied to infants and toddlers. The assumption of the goal circuit model is that learning involves encoding of sequences that achieve task goals and subgoals; thus, applying this model presupposes the presence of the ability to represent hierarchical goal representations explicitly.

Infants can process others' actions in a goal-directed manner; for example, direct their gaze to an actor's predicted goal object before the actor actually grasps that object (Kanakogi & Itakura, 2011; Monroy, Gerson, & Hunnius, 2017). However, even predictive processing might be explained by transitional probabilities between actions (i.e., after reaching for an object, adults often touch it). Thus, further studies are needed to confirm whether infants and toddlers can represent hierarchical goal representations "explicitly" like preschoolers and whether the characteristics of these representations match the assumptions of the goal circuit model. To clarify the developmental processes of everyday activities in a broader age range, these issues should be addressed in future studies.

Second, our review brings attention to the importance of everyday context in the development of executive functions. Executive functions are thought to be general-purpose control mechanisms and isolated from particular task situations (e.g., Carlson & Moses, 2001; Miyake et al., 2000; Miyake & Friedman, 2012). Owing to their nature, executive functions have been proposed as core mechanisms underlying cognitive development, socioemotional development, and academic skills (Best, Miller, & Naglieri, 2011; Carlson & Moses, 2001; Diamond, 2013). However, to explain the implementation of specific goal-directed behaviors in a specific context, any influences from previous experiences accumulated in the context cannot be ignored. Our review suggests that executive functions alone are insufficient to account for engaging in the control of repeated sequential actions and their interactions with the routine system should be considered. Implicit contextual representations underlying the routine system allow children to detect goal-irrelevant information, leading to triggering top-down control by executive functions. That is, the involvement of executive functions can be influenced by repeated experiences accumulated in a specific context.

It is possible that this view might link to how children develop executive functions. Recently, Doebel (2020) noted the importance of repeated experiences in a specific context to develop executive functions and argued that the development of executive functions is understood as the emergence of skills in exerting top-down control to attain specific goals. Specifically, children often encounter a situation in which a playmate takes one of their toys. Faced with this, they may want to hit the playmate or

take their toy back by force. However, with experience, they gradually accumulate the mental knowledge of what it feels like to get hit by someone and gain awareness of others' capacity to feel pain, which enables them to practice control and avoid hitting the playmate. That is, what children learn through repeated experiences in one context leads to engaging control in the service of specific goals in the same context. The accumulation of these processes contributes to the development of executive functions. Applying Doebel's novel framework to the domain of sequential actions, it is possible that everyday experiences that children have been learning, performing, and controlling in a variety of contexts may exercise and shape the development of executive functions. Recent developmental studies have highlighted the executive functions required in everyday activities through ecologically valid measures such as cooking, coloring activities, and getting ready for school (Fogel, Rosenblum, Hirsh, Chevignard, & Josman, 2020; Freier, Cooper, & Mareschal, 2017; Perone, Anderson, & Youatt, 2020). Using these paradigms, future studies should clarify the dynamic interactions between executive functions and the routine system.

Third, paying attention to contextual representations underlying routines generates a set of unique suggestions and predictions regarding everyday activities. Specifically, in the context of meal preparation, different recipes depend on different task contexts; but some actions are overlapped (e.g., making tea and making coffee). When children acquire routines for making tea and coffee, task contexts for making tea and coffee are represented similarly during overlapped common actions but represented distinctively

before selecting a context-depending action. As Yanaoka and Saito (2021) indicated, activating a task goal before selecting a context-depending action by reminders promotes the acquisition of routines. In contrast, after the acquisition of routines, contextual representations become attenuated during the performance of some common actions that do not rely on contextual information, leading to the occurrence of action slips (Botvinick & Plaut, 2004). Reminding a task goal during the performance of the common actions is also expected to prevent such action slips. Furthermore, Botvinick and Plaut (2002) argued that the flexible changes of contextual representations help us learn novel sequential actions that are similar to acquired routines. They reimplemented the model for making tea and coffee to learn a novel procedure of making cocoa, demonstrating that task contexts for making cocoa and making coffee are similarly represented during the performance of common subtasks (i.e., boiling water, preparing for a cup, etc.) but represented distinctively between context-dependent subtasks for adding coffee grounds and cocoa powder. Therefore, the novel sequential actions for making cocoa can be learned by reusing contextual representations of similar sequential actions for making coffee, not from scratch, and making the two sequential actions distinctive. This kind of generalization process has not been tested in young children; but it is worth investigating given that they need to master a vast multitude of sequential actions.

5. CONCLUSION

This review highlighted two critical aspects of the routine system in young children and proposed the developmental mechanism underlying the routine system. Contextual

information that supports routines in young children is flexibly represented so that goal-related behaviors are selected automatically. Furthermore, the acquisition of routines helps children detect goal-irrelevant information and fulfills the role of limiting the involvement of executive functions to when it is needed. The development of the routine system can be explained by the graded representation account and are shaped by statistical regularities and the development of executive functions. The aforementioned evidence suggests that young children's everyday activities are supported by complementary relations between executive function and routine acquisition, as indicated by Cooper et al. (2014). To further clarify the developmental processes of learning, performing, and controlling repeated sequential actions, future studies should examine the development of the routine system and its interaction with executive functions.

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