Transitions in Executive Function: Insights From Developmental Parallels Between Prospective Memory and Cognitive Flexibility

Caitlin E. V. Mahy[1] and Yuko Munakata[2]

[1]Brock University and [2]University of Colorado Boulder

ABSTRACT—*As children develop, they need to remember to carry out their intentions and overcome habits to switch flexibly to new ways of behaving. Developments in these domains—prospective memory and cognitive flexibility—are essential for children to function and predict important outcomes. Prospective memory and cognitive flexibility are similar in the psychological processes proposed to support them (particularly executive functions), in how they are measured, and in the behavioral transitions observed (e.g., dissociations between actions and intentions, and nonlinear developmental trajectories). In this article, we highlight how such parallels can inform debates about the specific executive functions and types of developments that support prospective memory, cognitive flexibility, and related future-oriented abilities, and can deepen understanding of executive function development more generally.*

KEYWORDS—*cognitive flexibility; prospective memory; executive control*

Caitlin E. V. Mahy, Department of Psychology, Brock University; Yuko Munakata, Department of Psychology and Neuroscience, University of Colorado Boulder.

The authors thank Jane Barker, Ryan Guild, Laura Michaelson, and other members of the Cognitive Development Center for helpful input. Writing of this article was supported by RO1 HD37163; research was supported by RO1 HD37163 and P50-MH079485, and an NSERC Postgraduate Scholarship and Swiss Government Scholarship to Caitlin E. V. Mahy.

Correspondence concerning this article should be addressed to Caitlin Mahy, Department of Psychology, Brock University, 500 Glenridge Ave., St. Catharines, ON, Canada L2S 3A1; e-mail: caitlin.mahy@brocku.ca.

DOI: 10.1111/cdep.12121

Children often need to remember to carry out tasks, such as returning a homework assignment. They also need to overcome habitual or prepotent behavior, like blurting out what they are thinking, to switch flexibly to new ways of thinking or behaving, such as waiting for their turn. These examples of prospective memory and cognitive flexibility, respectively, highlight fundamental aspects of cognitive development in academic and social contexts that predict important short- and long-term outcomes (1). Prospective memory and cognitive flexibility overlap in many ways, but few studies have attempted to draw parallels between these two areas.

In this article, we highlight parallels in developmental transitions that may advance understanding within each domain and of executive function, the goal-directed control of thought and action, more generally. First, we describe parallels in the psychological processes proposed to support prospective memory and cognitive flexibility (particularly executive functions), and parallels in the way they are measured. Then, we discuss debates and questions about which executive functions are critical, whether developmental changes in those executive functions contribute to developmental changes in behavior, and what form those changes in executive functions take. Next, we consider how some of these questions might be answered by considering behavioral parallels between prospective memory and cognitive flexibility. We focus on two transitions that occur as children age in both prospective memory and cognitive flexibility: a decrease in dissociations between actions and intentions, and a nonlinear pattern in the influence of distracting information on performance. Finally, we discuss implications for other future-oriented processes.

PARALLELS IN PSYCHOLOGICAL PROCESSES PROPOSED AND METHODS USED

Most theories of prospective memory, cognitive flexibility, and their development point to a central role for executive functions,

Child Development Perspectives

such as inhibition and working memory (2–5). Executive control relates highly to performance on prospective memory from preschool to adolescence (6, 7), and inhibition and working memory predict the age effect in children's performance on prospective memory (8, 9). Similarly, executive control relates to cognitive flexibility during development (10), including working memory and inhibition (11). The activation of prefrontal networks during prospective memory and cognitive flexibility tasks in children (12, 13) and adults (14, 15) is also consistent with the idea that these processes tap executive functions. Additional support comes from evidence that prospective memory and cognitive flexibility are improved when demands on executive function are reduced (7, 16–18). These manipulations may reduce demands on holding a secondary rule in working memory, and on inhibiting or shifting from a dominant task, though they may also free up cognitive resources more generally.

In terms of methodological parallels, both types of paradigms can include tasks that are primary (because they are ongoing in the case of prospective memory, and prepotent in the case of cognitive flexibility), with the measure of interest focusing on performance on a secondary task (prospective memory task or nondominant rule) in the face of the primary task. A standard event-based prospective memory paradigm involves forming an intention, followed by a delay filled with a distracting activity to promote forgetting, and then an ongoing task in which a cue signals that the prospective memory task should be performed (19). For example, children are asked to complete ongoing activities (e.g., to categorize cards into two categories or play a driving simulation game), but to perform a novel action when a prospective memory cue appears (e.g., an animal card appears or when a certain color of flower appears; 6, 17). At the end of the task, the children are asked to report the rules of the prospective memory task to confirm that they remember what they were supposed to do (the retrospective memory component of the prospective memory task). Cognitive flexibility is typically measured using tasks where a rule must be followed that conflicts with a prepotent alternative, based on prior experiences within the task or more generally (20). For example, in the dimensional change card sort (DCCS), participants sort cards by one dimension, then must switch to sort by a new dimension that conflicts with the prior dimension (21). Children are asked questions about the card-sorting rules to confirm that they understood what they were supposed to do.

Although similar, these paradigms are not simply variants of one another. One difference is a delay between forming and executing an intention in prospective memory tasks that can range from a few minutes to hours; during this time, no reference to the intention is made. Thus, prospective memory depends both on retrospective memory processes (storing an intention over a delay period, then retrieving the intention), as well as on prospective, executive-type processes (carrying out the intention at the appropriate time). In contrast, most tasks of cognitive flexibility demand that the action be executed immediately and often include reminders of the rules (e.g., children are reminded of the DCCS rules before each trial). Thus, cognitive flexibility may depend less on long-term memory than on actively maintaining rules for immediate action in working or short-term memory. Prospective memory by definition does not rely on actively maintaining the prospective memory intention in mind, as this would index a vigilance process (22). Although children could try to use a vigilance-like strategy in prospective memory tasks, this would likely harm their ongoing performance and so would be discouraged. Therefore, a key distinction between prospective memory and cognitive flexibility is whether an intention must be kept in mind for immediate action or stored for accomplishing a delayed intention.

QUESTIONS ABOUT THE ROLE OF EXECUTIVE FUNCTIONS

Although executive functions seem to play a central role in prospective memory and cognitive flexibility during development, what executive functions are most critical is debated (9, 23, 24). Moreover, while executive functions play a role at individual times during development, it is unclear whether developmental *changes* in executive functions play a causal role in the development of prospective memory and cognitive flexibility. Longitudinal studies that track each of these developmental trajectories could shed more light on their relationships, but such studies may be complicated by the fact that relationships with executive functions can seem to vary across development. For example, while most studies show that executive control predicts prospective memory performance from preschool to adolescence, in one study retrospective memory processes (and not the prospective component that relies on executive control) drove development of prospective memory between ages 7 and 10 (25). Similarly, while many studies show that executive control predicts cognitive flexibility across development, this relationship holds at age 8 but not age 12 (10) for one measure of executive control (the Flanker task, which requires responding to a central stimulus and ignoring surrounding flankers). More work is needed to examine specific executive functions that contribute to the development of prospective memory and cognitive flexibility from childhood into adolescence.

If changes in executive functions play a causal role in the development of prospective memory and cognitive flexibility, what form do those changes in executive functions take? Developments in executive function have been characterized in diverse ways, including the differentiation of distinct executive functions (26), the temporal dynamics of how control is engaged (27), and the neural systems recruited (2, 12). However, it is unclear how such developmental changes in executive function relate to developments in prospective memory and cognitive flexibility. Other developing abilities may also contribute to improvements in prospective memory and cognitive flexibility, such as increases in complexity of mental representation (including representation of task goals and strategies) and advances in children's ability to monitor their own cognitive processing (28).

BEHAVIORAL PARALLELS AND IMPLICATIONS FOR QUESTIONS

Two developmental transitions occur with age in both prospective memory and cognitive flexibility: a decrease in dissociations between actions and intention, and a nonlinear pattern in the effects of distracting information on performance. These parallels may suggest ways to integrate these domains and inform debates about which executive functions and what types of developmental changes in executive functions are critical to the development of prospective memory and cognitive flexibility.

Dissociations

Young children often fail to carry out their intentions (in prospective memory paradigms) or perseverate on an incorrect response (in cognitive flexibility tasks), despite knowing what they are supposed to do (19, 21). However, with age, children can use their knowledge to inform actions and often behave in accordance with their knowledge. The dissociations between actions and knowledge have been interpreted distinctly across the two domains in ways that may inform each domain. For example, the fact that children can answer questions correctly in tasks of cognitive flexibility (e.g., "Where do trucks go in the shape game?"), together with the fact that the task rules are often repeated, led researchers to conclude that problems in memory for the rule alone cannot explain children's perseverative errors (29), and to characterize these dissociations as *abulic*, distinguishing between what children know and how they act on that knowledge (21).

In contrast, the fact that children can correctly answer questions in prospective memory paradigms (e.g., "What were you supposed to do when you saw an animal card?") has *not* led researchers to conclude that failures of memory play no role in prospective memory errors. Instead, these questions are viewed as tapping one form of memory that is successful (retrospective memory), while the ability to carry out intentions is viewed as tapping a distinct form of memory that is less successful (prospective memory). To what extent does this distinction between retrospective and prospective memory contribute to the dissociations in tasks of cognitive flexibility? Failures of prospective memory could contribute to children perseverating in situations where rules are not repeated often or in cases where children do not attend to the repetition of rules, while retrospective memory could support correct answers to direct questions about rules.

Conversely, an alternative interpretation of dissociations in children's cognitive flexibility may be relevant to understanding dissociations in prospective memory. Specifically, children's *knowledge-action* dissociations can be understood more thoroughly in terms of the amount of conflict that needs to be resolved to succeed at a task. Knowledge questions typically focus on only the relevant feature, so that no conflict needs to be resolved, whereas action measures typically require sorting by the relevant feature in the face of conflicting information from a previously relevant feature (e.g., a red truck gets sorted in one bin based on its shape, but in another bin based on the prior rule of color). When the amount of conflict is equated across measures of action and knowledge (e.g., by asking children, "Where do red trucks go in the shape game?"), dissociations disappear: Children perseverate at similar levels across measures (30). To what extent does the amount of conflict that needs to be resolved contribute to dissociations observed in prospective memory tasks? For example, failures to resolve conflict could contribute to children's failures to carry out their intentions in the face of an ongoing (potentially conflicting) task, while still allowing them to succeed when queried about those intentions in the absence of information about that ongoing task. This possibility could be tested by equating prospective and retrospective components of tasks of prospective memory in terms of the amount of conflict that needs to be resolved (e.g., by asking participants at the end of the study to report the full set of task rules).

In this way, behavioral dissociations in both prospective memory and cognitive flexibility suggest new answers to test regarding which executive functions are critical during development: conflict resolution processes in the case of prospective memory, and prospective memory processes in the case of cognitive flexibility.

Nonlinear Development and Temporal Dynamics of Control

In both cognitive flexibility and prospective memory, children improve notably across the first decade of life (17, 20). Children accomplish prospective memory tasks more accurately, switch between using two rules more flexibly, and complete such tasks more efficiently and with greater speed. However, in both domains, introducing distracting information can impair the performance of more advanced children *more* than that of less advanced children (31, 32). For example, 6-year-olds who can switch flexibly between rules in a version of the DCCS task react more quickly and are thus more prepared on a working memory task than children who fail to switch rules and perseverate. However, when children are distracted by a secondary task (counting backwards and tapping hands) during the working memory task, this pattern reverses: Children who switch flexibly react more slowly on the working memory task than children who perseverate (31). Similarly, when children are asked to refuel the tank of a car each minute while navigating traffic in a driving simulation game, older children's ability to monitor time for the prospective memory cue suffers more than younger children's from a concurrent secondary task (e.g., N-back, 32; or judging gender of words spoken by opposite-gender voices, 33). Thus, rather than children improving monotonically with age or level, as expected, their performance can diminish with age or level in the face of distraction.

These nonlinear patterns can inform us about the processes supporting children's development (see special issue of *Journal of Cognition and Development*, January–March 2004). In the cases of cognitive flexibility and prospective memory, these patterns may reflect a developmental change in the temporal dynamics of control, and relative costs and benefits associated with distinct forms of control (see special section of *Neuropsychologia*, September 2014). Specifically, children seem to transition from relying on reactive forms of control (engaged in the moment, as needed) to relying increasingly on proactive forms of control (engaged in anticipation of needing the proactive forms of control; 34). Proactive control can support more efficient preparedness, given its anticipatory nature, but can also be more susceptible to distraction because it requires actively maintaining information across time rather than engaging control on the fly. From this perspective, the performance of more advanced children may suffer from a secondary task more than that of less advanced children, because the more advanced children approach the task with a proactive strategy that fails in the face of distraction, whereas the less advanced children rely more on reactive processes that are recruited as needed.

These ideas are consistent with other evidence on children's cognitive flexibility (35) and lead to testable predictions about developmental changes in children's prospective memory. For example, older children may be more likely than younger children to proactively use the delay between forming an intention and the phases of executing it, or time during the ongoing task, for strategies such as processes involved in monitoring intentions. Therefore, older children's prospective memory may be more disrupted by a difficult activity during the delay or a difficult ongoing task, whereas younger children's prospective memory may be less disrupted by these distracting activities because they rely on reactive control. These predictions offer a possible way to integrate these two fields and further investigate what types of developments in executive function may drive changes in prospective memory, cognitive flexibility, and other domains.

OTHER FUTURE-ORIENTED PROCESSES

The implications of parallels between prospective memory and cognitive flexibility may be relevant to related domains, such as delaying gratification, a future-oriented process like prospective memory. Delaying gratification requires resisting the temptation of a small reward immediately in favor of a larger reward later. The transition from reactive to proactive control, which is highlighted by nonlinear developmental trajectories in prospective memory and cognitive flexibility, may also influence how children delay gratification. The ability to inhibit prepotent actions apparently depends on a proactive process of monitoring the environment for signals that indicate the need to change course (27), so children's inhibitory control can be improved by practicing monitoring for such signals proactively (36). Such proactive monitoring (e.g., for the arrival of a reward) might also be central to children's abilities to stop themselves from acting on immediately available rewards.

CONCLUSION

Studies of cognitive flexibility and prospective memory have proceeded in two largely independent realms. However, they can inform each other, given similarities in theory, behavior, and method. In this article, we discuss questions common to these two domains and others regarding specific executive functions and types of developments, and we present ideas about how parallels between prospective memory and cognitive flexibility might inform these questions. For example, behavioral dissociations in both prospective memory and cognitive flexibility suggest the value of testing the role of conflict-resolution processes in prospective memory, and the role of prospective memory processes in cognitive flexibility. Additionally, nonlinear developmental trajectories in the effects of distracting information on prospective memory and cognitive flexibility highlight how developmental changes in the temporal dynamics of control may drive changes across these domains. Such changes from reactive to increasingly proactive control may relate to many other developments in childhood, such as the ability to delay gratification. We hope this article encourages researchers to think about the kind of parallels we have highlighted, and how they may inform an understanding of developmental changes in prospective memory, cognitive flexibility, executive function, and other domains.

REFERENCES

1. Shoda, Y., Mischel, W., & Peake, P. K. (1990). Predicting adolescent cognitive and self-regulatory competencies from preschool delay of gratification: Identifying diagnostic conditions. *Developmental Psychology*, *26*, 978–986. doi:10.1037/0012-1649.26.6.978
2. Bunge, S. A., & Zelazo, P. D. (2006). A brain-based account of the development of rule use in childhood. *Current Directions in Psychological Science*, *15*, 118–121. doi:10.1111/j.0963-7214.2006.00419.x
3. McDaniel, M. A., & Einstein, G. O. (2000). Strategic and automatic processes in prospective memory retrieval: A multiprocess framework. *Applied Cognitive Psychology*, *14*, S127–S144. doi:10.1002/acp.775
4. Mahy, C. E. V., Moses, L. J., & Kliegel, M. (2014). The development of prospective memory in children: An executive framework. *Developmental Review*, *34*, 305–326. doi:10.1016/j.dr.2014.08.001
5. Munakata, Y., Snyder, H. R., & Chatham, C. H. (2012). Developing cognitive control: Three key transitions. *Current Directions in Psychological Science*, *21*, 71–77. doi:10.1177/0963721412436807
6. Mahy, C. E. V., & Moses, L. J. (2011). Executive functioning and prospective memory in young children. *Cognitive Development*, *26*, 269–281. doi:10.1016/j.cogdev.2011.06.002
7. Wang, L., Kliegel, M., Yang, Z., & Liu, W. (2006). Prospective memory performance across adolescence. *The Journal of Genetic Psychology*, *167*, 179–188. doi:10.3200/GNTP.167.2.179-188

8. Kretschmer, A., Voigt, B., Friedrich, S., Pfeiffer, K., & Kliegel, M. (2013). Time-based prospective memory in young children—Exploring executive functions as a developmental mechanism. *Child Neuropsychology*, *20*, 662–676. doi:10.1080/09297049.2013.841881
9. Mahy, C. E. V., Moses, L. J., & Kliegel, M. (2014). The impact of age, ongoing task difficulty, and cue salience on preschoolers' prospective memory performance: The role of executive function. *Journal of Experimental Child Psychology*, *127*, 52–64. doi:10.1016/j.jecp.2014.01.006
10. Harms, M., Zayas, V., Meltzoff, A., & Carlson, S. (2014). Stability of executive function and predictions to adaptive behavior from middle childhood to pre-adolescence. *Frontiers in Psychology*, *5*, 331. doi:10.3389/fpsyg.2014.00331
11. Zelazo, P. D., Carlson, S. M., & Kesek, A. (2008). The development of executive function in childhood. In C. Nelson & M. Luciana (Eds.), *Handbook of developmental cognitive neuroscience* (2nd ed., pp. 553–574). Cambridge, MA: MIT Press.
12. Ezekiel, F., Bosma, R., & Morton, J. B. (2013). Dimensional change card sort performance associated with age-related differences in functional connectivity of lateral prefrontal cortex. *Developmental Cognitive Neuroscience*, *5*, 40–50. doi:10.1016/j.dcn.2012.12.001
13. Moriguchi, Y., & Hiraki, K. (2011). Longitudinal development of prefrontal function during early childhood. *Developmental Cognitive Neuroscience*, *1*, 153–162. doi:10.1016/j.dcn.2010.12.004
14. Braver, T. S., Paxton, J. L., Locke, H. S., & Barch, D. M. (2009). Flexible neural mechanisms of cognitive control within human prefrontal cortex. *Proceedings of the National Academy of Sciences of the United States of America*, *106*, 7351–7356. doi:10.1073/pnas.0808187106
15. West, R., & Krompinger, J. (2005). Neural correlates of prospective and retrospective memory. *Neuropsychologia*, *43*, 418–433. doi:10.1016/j.neuropsychologia.2004.06.012
16. Fisher, A. V. (2011). Automatic shifts of attention in the dimensional change card sort task: Subtle changes in task materials lead to flexible switching. *Journal of Experimental Child Psychology*, *108*, 211–219. doi:10.1016/j.jecp.2010.07.001
17. Kliegel, M., Mahy, C. E. V., Voigt, B., Henry, J. D., Rendell, P. G., & Aberle, I. (2013). The development of prospective memory in young school children: The impact of ongoing task absorption, cue salience, and cue centrality. *Journal of Experimental Child Psychology*, *116*, 792–810. doi:10.1016/j.jecp.2013.07.012
18. Towse, J. N., Redbond, J., Houston-Price, C. M., & Cook, S. (2000). Understanding the dimensional change card sort: Perspectives from task success and failure. *Cognitive Development*, *15*, 347–365. doi:10.1016/S0885-2014(00)00021-6
19. Kvavilashvili, L., Messer, D. J., & Ebdon, P. (2001). Prospective memory in children: The effects of age and task interruption. *Developmental Psychology*, *37*, 418–430. doi:10.1037/0012-1649.37.3.418
20. Carlson, S. M. (2005). Developmentally sensitive measures of executive function in preschool children. *Developmental Neuropsychology*, *28*, 595–616. doi:10.1207/s15326942dn2802_3
21. Zelazo, P. D., Frye, D., & Rapus, T. (1996). An age-related dissociation between knowing rules and using them. *Cognitive Development*, *11*, 37–63. doi:10.1016/S0885-2014(96)90027-1
22. Brandimonte, M. A., Ferrante, D., Feresin, C., & Delbello, R. (2001). Dissociating prospective memory from vigilance processes. *Psicológica*, *22*, 97–113.
23. Chevalier, N., & Blaye, A. (2008). Setting goals to switch between tasks: Effect of cue transparency on children's cognitive flexibility. *Developmental Psychology*, *45*, 782–797. doi:10.1037/a0015409
24. Kloo, D., Perner, J., Aichhorn, M., & Schmidhuber, N. (2010). Perspective taking and cognitive flexibility in the dimensional change card sorting (DCCS) task. *Cognitive Development*, *25*, 208–217. doi:10.1016/j.cogdev.2010.06.001
25. Smith, R. E., Bayen, U. J., & Martin, C. (2010). The cognitive processes underlying event-based prospective memory in school-age children and young adults: A formal model-based study. *Developmental Psychology*, *46*, 230–244. doi:10.1037/a0017100
26. Wiebe, S. A., Sheffield, T., Nelson, J. M., Clark, C. A., Chevalier, N., & Espy, K. A. (2011). The structure of executive function in 3-year-olds. *Journal of Experimental Child Psychology*, *108*, 436–452. doi:10.1016/j.jecp.2010.08.008
27. Chatham, C. H., Claus, E. D., Kim, A., Curran, T., Banich, M. T., & Munakata, Y. (2012). Cognitive control reflects context monitoring, not motoric stopping, in response inhibition. *PLoS ONE*, *7*, e31546. doi:10.1371/journal.pone.0031546
28. Lyons, K. E., & Zelazo, P. D. (2010). Monitoring, metacognition, and executive function: Elucidating the role of self-reflection in the development of self-regulation. *Advances in Child Development and Behavior*, *40*, 379–412. doi:10.1016/B978-0-12-386491-8.00010-4
29. Diamond, A., Carlson, S. M., & Beck, D. M. (2005). Preschool children's performance in task switching on the dimensional change card sort task: Separating the dimensions aids the ability to switch. *Developmental Neuropsychology*, *28*, 689–729. doi:10.1207/s15326942dn2802_7
30. Munakata, Y., & Yerys, B. E. (2001). All together now: When dissociations between knowledge and action disappear. *Psychological Science*, *12*, 335–337. doi:10.1111/1467-9280.00361
31. Blackwell, K. A., & Munakata, Y. (2014). Costs and benefits linked to developments in cognitive control. *Developmental Science*, *17*, 203–211. doi:10.1111/desc.12113
32. Voigt, B., Mahy, C. E. V., Ellis, J., Schnitzspahn, K., Altgassen, M., & Kliegel, M. (2014). The development of time-based prospective memory in childhood: The role of working memory updating. *Developmental Psychology*, *50*, 2393–2404. doi:10.1037/a0037491
33. Mahy, C. E. V., Voigt, B., Ballhausen, N., Schnitzspahn, K., Ellis, J., & Kliegel, M. (in press). The impact of cognitive control on children's goal monitoring in a time-based prospective memory task. *Child Neuropsychology*. doi:10.1080/09297049.2014.967202
34. Chatham, C. H., Frank, M. J., & Munakata, Y. (2009). Pupillometric and behavioral markers of a developmental shift in the temporal dynamics of cognitive control. *Proceedings of the National Academy of Sciences of the United States of America*, *106*, 5529–5533. doi:10.1073/pnas.0810002106
35. Blackwell, K. A., Chatham, C. H., Wiseheart, M., & Munakata, Y. (2014). A developmental window into trade-offs in executive function: The case of task switching versus response inhibition in 6-year-olds. *Neuropsychologia*, *62*, 356–364. doi:10.1016/j.neuropsychologia.2014.04.016
36. Chevalier, N., Chatham, C. H., & Munakata, Y. (2014). The practice of going helps children to stop: The importance of context monitoring in inhibitory control. *Journal of Experimental Psychology: General*, *143*, 959–965. doi:10.1037/a0035868