



## Schema processing across the Lifespan: From theory to Applications

Irene P. Kan, R. Shayna Rosenbaum & Mieke Verfaellie

To cite this article: Irene P. Kan, R. Shayna Rosenbaum & Mieke Verfaellie (2020): Schema processing across the Lifespan: From theory to Applications, Cognitive Neuropsychology, DOI: [10.1080/02643294.2020.1736019](https://doi.org/10.1080/02643294.2020.1736019)

To link to this article: <https://doi.org/10.1080/02643294.2020.1736019>



Published online: 28 Feb 2020.



Submit your article to this journal [↗](#)



Article views: 1



View related articles [↗](#)



View Crossmark data [↗](#)



## Schema processing across the Lifespan: From theory to Applications

Irene P. Kan<sup>a</sup>, R. Shayna Rosenbaum<sup>b,c</sup> and Mieke Verfaellie<sup>d</sup>

<sup>a</sup>Department of Psychological & Brain Sciences, Villanova University, Villanova, PA, USA; <sup>b</sup>Department of Psychology, Vision: Science to Applications (VISTA) Program, York University, Toronto, Canada; <sup>c</sup>Rotman Research Institute, Baycrest, Toronto, Canada; <sup>d</sup>Memory Disorders Research Center, VA Boston Healthcare System and Boston University School of Medicine, Boston, MA, USA

**ARTICLE HISTORY** Received 10 February 2020; Accepted 19 February 2020

**KEYWORDS** Schema; memory; inferential reasoning; hippocampus; medial prefrontal cortex

### Overview

In 1932, Bartlett introduced the term “schema” to Psychology and defined it as “an active organization of past reactions, or of past experiences ...” (p. 201). Across repeated, albeit slightly different, experiences, we extract similarities and regularities and use these building blocks as scaffolding for future encounters. Since Bartlett’s proposal, the construct of schema has become central in many domains of cognition, including development, learning and memory, and decision making (e.g., Anderson, 1984; Euston, Gruber, & Mcnaughton, 2012; Fellows, 2016; Ghosh & Gilboa, 2014; Kumaran, 2013; Mandler, 1992; Piaget, 1954; van Kesteren, Ruiters, Fernández, & Henson, 2012). Although the precise definition of “schema” varies, the general consensus among researchers is that schemas are associative, superordinate knowledge structures that represent abstracted commonalities across a number of instances. Schemas are also widely viewed as playing a key role in guiding our current behaviour and thoughts and, in turn, are modified by new experiences (e.g., Bartlett, 1932; Fernández & Morris, 2018; Ghosh & Gilboa, 2014; Preston & Eichenbaum, 2013; van Kesteren et al., 2012).

The papers in this Special Issue of *Cognitive Neuropsychology* provide a broad perspective on how schemas impact higher-order cognition, building on foundational work in cognitive psychology, clinical neuropsychology, and cognitive neuroscience. Several empirical papers examine how schematic representations are formed, updated, and activated in ways that can facilitate new learning and other cognitive processes, but under certain circumstances, may

also hinder performance (Pudhyyidath, Roome, Coughlin, Nguyen, & Preston, 2019; Raykov, Keidel, Oakhill, & Bird, 2019; Ryan et al., 2019; Webb & Dennis, 2019; Zhang, Johndro, Budson, & Gutches, 2019). These effects are examined in several populations, including healthy children, young adults, older adults, and individuals with amnesic mild cognitive impairment. In two review/theory papers, the authors use the construct of schema as an interpretive framework for understanding different aspects of cognition (Davis, Altmann, & Yee, 2019; Yu, Kan, & Kable, 2019). Together, these papers provide new insights into the cognitive architecture and neural bases of schematic influence.

### Schema formation in children and adults

Focusing on schematic representations of other people, Raykov et al. (2019) ask how novel person-specific schematic knowledge is neurally instantiated. To induce schematic knowledge, participants were exposed to six episodes of one of two previously unfamiliar television shows. At the end of the acquisition period, subjects were shown pictures of the main characters of both the trained show and the unfamiliar show. Consistent with prior neuroimaging investigations of schematic processing that utilize other paradigms (e.g., Baldassano, Hasson, & Norman, 2018; Liu, Grady, & Moscovitch, 2016; Zeithamova, Dominick, & Preston, 2012), Raykov and colleagues observe training effects in ventromedial prefrontal cortex (vmPFC), retrosplenial cortex, and to a lesser extent, hippocampus, with these regions showing

increased activation for trained compared to untrained characters. In contrast to theoretical frameworks that propose competing roles for vmPFC and hippocampus during schematic processing (e.g., SLIMM, van Kesteren et al., 2012), Raykov and colleagues report similar response profiles across these regions, suggesting that these regions work together in mediating schematic effects (see also Preston & Eichenbaum, 2013; Robin & Moscovitch, 2017). Examining representational similarity, the authors further demonstrate that character identity can be decoded in vmPFC, but not in hippocampus. This is the case regardless of prior training with the characters, leaving open the question of how newly acquired schematic knowledge is coded in the brain.

Current evidence on the development of schemas suggests that although young children form temporal, spatial, and event associations in a similar manner as adults (i.e., extracting regularities over multiple instances), their schemas tend to be less elaborate and also less flexible than those formed by adults, even when controlling for differences in prior experience (e.g., Farrar & Goodman, 1992; Price & Goodman, 1990). To further characterize these differences, Pudhiyidath et al. (2019) examine the ability of children, adolescents, and young adults to learn a temporal community structure and to use that structure to guide decisions in a non-temporal reasoning task (see below). By watching the sequential presentation of cartoon characters, with the same characters repeatedly occurring in temporal proximity, participants acquired knowledge about the temporal communities to which the characters belonged. On a forced choice task assessing explicit knowledge of the temporal schema, increasing age was associated with greater temporal knowledge. The authors postulate that the protracted development of temporal schema formation may reflect ongoing maturation of hippocampal and prefrontal mechanisms, but precisely how these regions interact remains to be established.

### **Schema effects on memory and reasoning**

Three studies examine the extent to which different types of schemas, whether newly or pre-experimentally formed, impact episodic memory. Zhang and colleagues (2019) focus on the self-schema—the sum of one's own preferences, personality traits, actions, and

goals exhibited over multiple personal experiences. The authors sought to activate the self-schema in two ways: (a) by means of a conventional trial-by-trial self-reference procedure, where each word is processed in reference to the self, and (b) by using an autobiographical thought induction procedure, where subjects recalled autobiographical memories prior to encoding the word list. Subjects' recognition of the stimuli was later tested. In addition to young adults, the authors tested older adults with and without a diagnosis of amnesic mild cognitive impairment (aMCI), which is associated with declines in hippocampal function and episodic memory. Relative to a non-self-referential control condition, the trial-by-trial self-reference procedure led to improved recognition memory in all groups. In contrast, the novel autobiographical thought induction condition resulted in reduced memory performance, primarily due to an increase in false alarms in all groups. The authors suggest that the beneficial effects of self-referential processing may be temporally limited, where it can be observed on a trial-by-trial basis but not through a schema induced for a prolonged period.

Episodic memory benefits associated with schematic knowledge are also apparent in the study by Raykov and colleagues (2019), in which participants developed schemas for characters in a television show. In one task, participants were given a recognition memory test in the scanner for the specific images of trained and untrained characters to which they had been exposed. In another task, they viewed short videos of unseen episodes from the trained show and short videos from the untrained show, followed by forced choice questions that assessed memory of the video clips. Consistent with prior behavioural findings, subjects had better memory for pictures and video clips from trained than untrained shows. Surprisingly, however, connectivity analyses did not reveal modulation by training condition for either vmPFC or hippocampus.

Taking a somewhat different approach, Webb and Dennis (2019) focus on the effects of complex scene schemas on memory for information that supports the scene (i.e., schema-consistent information) and information that naturally fits into the scene but does not support the schema (i.e., non-schematic information). They find that schema-consistent items are associated with higher hit rates than non-schema items, possibly reflecting the privileged encoding of

schema-consistent items. But this is accompanied by higher false alarm rates for schema-consistent items, yielding equivalent memory accuracy for schema-consistent and non-schema information. In a follow-up experiment, Webb and Dennis demonstrate that cueing participants to attend to non-schema items can mitigate the prioritization of schema-consistent information. Notably, such a manipulation improves memory for non-schema items without disrupting memory for schema-consistent items—a pattern apparent in both younger and older adults. These results at the same time demonstrate the impact of goal-directed mechanisms at encoding and the pervasive influence of schemas.

Schemas can also exert effects on inference tasks that require hippocampally-mediated relational processes. In a typical transitivity paradigm, participants learn to associate a sample stimulus with one of two choice stimuli. Across multiple trials of premise pairs (e.g., learning that A goes with B but not X, and B goes with C but not Y), participants eventually infer that the stimuli belong to one of two different groups based on their associations with one another (e.g., if given A, choose C, which is from the same group, but not Y, which belongs to a different group). Ryan and colleagues (2019) use such a task, adapted from the rodent literature, but vary the degree of prior semantic relatedness of studied and inferred pairs of stimuli. The items used are known objects, either with arbitrary relations or well-established previously known relations. The authors demonstrate that older adults' ability to make transitive inferences is facilitated when they have prior knowledge of the relations among premise pairs. This schematic scaffold effect is present both in healthy older adults and in adults at risk for cognitive decline, suggesting a promising avenue for intervention in cognitive aging. However, its absence in adults diagnosed with aMCI sets limits on the extent of the effect and points to its dependence on hippocampal-medial prefrontal cortex circuitry, which may be affected in aMCI (e.g., Ries et al., 2012).

At the other end of the developmental spectrum, Pudhivadath and colleagues (2019) show that inductive reasoning also benefits from the acquisition of schematic knowledge. Participants' ability to flexibly use the temporal community structure they acquired during the experiment was tested by presenting them with a non-temporal fact about one character

and assessing whether they could apply that knowledge to a character from the same temporal community. Reasoning decisions indeed were influenced by the knowledge participants had acquired about temporal relationships, and greater knowledge of temporal schema was associated with a greater bias to infer that characters from the same community shared non-temporal features. These studies provide important insights into schematic effects in early development and their breakdown in aging and age-related disease, with implications for workable interventions.

### Schema as an interpretive framework

In recent neuroimaging studies, the vmPFC has emerged as an important region in the instantiation and processing of schemas. However, the picture from the neuropsychological literature is less coherent. Damage to the ventromedial frontal lobes (VMF, which includes both vmPFC and orbitofrontal cortex) has been linked to deficits in a wide variety of cognitive domains, including executive function, valuation, decision making, memory, emotion, social cognition, and the self. In a systematic review of human lesion studies of patients with VMF damage published within the last 20 years, Yu and colleagues (2019) advance a framework that can potentially unify the impairments observed across these seemingly disparate domains. They propose that VMF plays an important role in representing the structure of the world, and such representations are abstract and flexible, enabling inferences about relationships. These characteristics are similar to the conceptions of "cognitive map", "state space" and "schema", ideas that are prominent in the learning, decision making, and memory domains. Furthermore, VMF's connectivity to multiple sensory regions and to the medial temporal lobes enables VMF to represent such abstract structures and to integrate information across different sources. The authors propose that impaired schematic or state representations can account for the cognitive deficits observed across the various domains.

Finally, Davis and colleagues (2019) propose that reference to schema knowledge provides a useful theoretical lens for understanding differences between concrete and abstract concepts. The authors argue that the difference between concrete

and abstract concepts is best thought of as a difference in the degree of shared situations, called “situational systematicity”, where concrete concepts have higher situational systematicity than abstract concepts. Building on recent neurobiological models of schemas (e.g., Gilboa & Marlatte, 2017; van Kesteren et al., 2012; van Kesteren et al., 2013), the authors further propose a model of schema control circuitry that includes the angular gyrus, medial prefrontal cortex (mPFC), inferior frontal gyrus, and hippocampus. These distinct brain regions interact in a continuous and interactive way. Under conditions of low situational systematicity (i.e., for abstract concepts), multiple schemas compatible with the concept will be activated, and these regions work competitively to minimize the influence of task-irrelevant information. However, when situational systematicity is high (i.e., for concrete concepts), the need for mPFC-driven inhibition is lower because there will be fewer competing activated schemas. In sum, the extent to which mPFC is engaged, along with its inhibitory influence over the hippocampus, is determined by the degree of situational systematicity. This work challenges the traditional consideration of concepts along a continuum of abstractness – concreteness and provides a model of neural circuitry for a schema control network.

### Concluding comments

The collection of papers in this Special Issue of *Cognitive Neuropsychology* illustrates the fact that the process of schema formation is automatic, and the influence of schemas is pervasive and also dynamic. Raykov and colleagues (2019) and Pudhiyidath and colleagues (2019) introduced experimental paradigms that can be used to induce schema formation naturally. The underlying processes involved (e.g., extracting similarities across multiple experiences, associative memory structure) appear to be quite similar for both adults and children and also across the domains of person-specific schemas and temporal schemas. Once the schemas are formed, schematic processing often bestows benefits on memory and reasoning, but under some circumstances it can have detrimental effects, as reflected in increased false alarm rates in recognition memory. The findings by Webb and Dennis (2019) clearly illustrate that there are boundary conditions to the beneficial

schematic effects on recognition memory. In particular, when lure items also strongly activate a schema, the enhanced familiarity associated with schematic information may no longer be useful. This may be more likely to occur when a schema is provided in the context of the experiment than when participants need to infer the schema on their own, as was the case in Raykov and colleagues (2019) and Zhang and colleagues (2019).

Another factor that may moderate schematic effects relates to the specificity of the activated schema. This may explain the differential effects of the traditional trial-by-trial self-reference and autobiographical thought induction procedures employed by Zhang and colleagues (2019). In the traditional procedure, participants are directed to process each word in a specific manner (i.e., to determine whether a word describes themselves), and such processing may be particularly effective in promoting the anchoring of the stimulus word to the self-schema. In contrast, the autobiographical thought induction paradigm encourages subjects to engage in a sustained mode of self-referencing. When a stimulus word is presented, the relevant aspect of the self-schema may not be readily activated, thus rendering the scaffolding less effective.

Turning to the data from individuals with aMCI, it is notable that although inference ability suffers (Ryan et al., 2019), recognition memory enhancements associated with self-referential processing remain present (Zhang et al., 2019). One possibility is that inference requires a level of flexible processing of schema information that is not necessary for self-referential processing. This flexibility requires protracted brain maturation (Pudhiyidath et al., 2019) and may also be affected by age-related degeneration. Another possibility is that the ability to benefit from schematic processing depends on the strength of the schema. Although not explicitly manipulated in the studies in this issue, one could argue that the self-schema is likely to be the strongest schema in long-term memory. Perhaps the beneficial effects of schematic processing are evident in aMCI only when the scaffolding is the strongest.

A number of studies in this issue point to hippocampal-medial prefrontal interactions as being critical in mediating schematic scaffolding effects, but the precise nature of these interactions remains unclear. Whereas the findings by Raykov and colleagues

(2019) suggest that these regions work cooperatively, Davis and colleagues (2019) propose that these regions inhibit each other during schema processing. The conditions under which each of these dynamic models applies remain to be further elucidated; doing so could help explain situations in which performance does not benefit from schematic knowledge, such as in the aMCI group tested by Ryan and colleagues (2019). Moreover, the influence and timing of contributions from neocortical regions outside of medial prefrontal cortex add another layer of complexity that remains to be worked out. As suggested by Yu and colleagues (2019), a greater focus on the functional networks interconnected with medial prefrontal cortex, rather than individual regions, could be particularly helpful in this regard, as would methods that are better able to capture brain dynamics, such as MEG and EEG.

Investigations of schemas in humans have primarily been in relation to event-related knowledge structures within the domain of verbal memory. In the animal literature, however, investigations that employ spatial navigation paradigms are more common (e.g., McKenzie, Robinson, Herrera, Churchill, & Eichenbaum, 2013; Tse et al., 2007). The recent discovery of “schema” cells in the macaque has brought renewed attention to the possibility of spatial schemas in humans (Baraduc, Duhamel, & Wirth, 2019). Only a handful of human studies have been designed to track spatial schema instantiation (e.g., Marchette, Ryan, & Epstein, 2017; van Kesteren, Brown, & Wagner, 2018). Another question concerns the relevance of schemas to understanding preserved aspects of remote spatial memories following hippocampal lesions (e.g., Herdman, Calarco, Moscovitch, Hirshhorn, & Rosenbaum, 2015; Winocur, Moscovitch, Rosenbaum, & Sekeres, 2010), and if and how these representations map onto distinctions between allocentric and egocentric coordinates or relate to cognitive maps (Epstein, Patai, Julian, & Spiers, 2017). Future research aimed at identifying the core features of environments that form schematized spatial knowledge and how spatial schemas are organized at the neural level is warranted. Computational approaches are promising in this regard (e.g., Filomena, Verstegen, & Manley, 2019).

There is a longer history of research on schemas giving rise to false memory and memory distortions (Bartlett, 1932; Deese, 1959; Ghosh & Gilboa, 2014;

Roediger & McDermott, 1995). Although not covered extensively in the current Special Issue, this work has implications for understanding the limits of training paradigms to enhance memory in real-world settings and for addressing issues of societal concern, such as fake news and deepfakes, which refers to the use of machine learning of a person’s vocal, facial, and body dynamics based on audio and video recordings to produce occurrences that never actually took place (Rini, 2019). There is the suggestion that fake news and deepfakes are difficult to disregard or extinguish given their rapid and far reach via the internet and social media (Vosoughi, Roy, & Aral, 2018). The growing challenge in deciphering true from false information may facilitate the incorporation of false information into schemas, which, in turn, influences the way in which new information is perceived and remembered.

In summary, great strides have been made in defining schemas, understanding their neural substrate, and identifying how they build up in development and break down in older age and in neurological conditions. As reflected in the collection of articles in this Special Issue, an interdisciplinary, multimethod approach is needed to further advance the field. For now, the new data and theoretical reviews on schemas presented in this issue of *Cognitive Neuropsychology* have the potential to generate testable hypotheses and, ultimately, a unifying theory of hippocampal-neocortical interactions that bridges animal and human models, and basic and applied research.

### Disclosure statement

No potential conflict of interest was reported by the author(s).

### References

- Anderson, R. C. (1984). Role of the reader’s schema in comprehension, learning, and memory. In R. Anderson, J. Osborn, & R. Tierney (Eds.), *Theoretical models and processes of reading* (4th ed.). Newark: International Reading Association.
- Baldassano, C., Hasson, U., & Norman, K. A. (2018). Representation of real-world event schemas during narrative perception. *The Journal of Neuroscience*, 38, 9689–9699. doi:10.1523/JNEUROSCI.0251-18.2018

- Baraduc, P., Duhamel, J. R., & Wirth, S. (2019). Schema cells in the macaque hippocampus. *Science*, *363*, 635–639. doi:10.1126/science.aav5404
- Bartlett, F. C. (1932). *Remembering: A study in experimental and social psychology*. New York: Cambridge University Press.
- Davis, C. P., Altmann, G. T. M., & Yee, E. (2019). Situational systematicity: A role for schema in understanding the differences between abstract and concrete concepts. *Cognitive Neuropsychology*. doi:10.1080/02643294.2019.1710124
- Deese, J. (1959). On the prediction of occurrence of particular verbal intrusions in immediate recall. *Journal of Experimental Psychology*, *58*, 17–22. doi:10.1037/h0046671
- Epstein, R. A., Patai, E. Z., Julian, J. B., & Spiers, H. J. (2017). The cognitive map in humans: Spatial navigation and beyond. *Nature Neuroscience*, *20*, 1504–1513. doi:10.1038/nn.4656
- Euston, D. R., Gruber, A. J., & McNaughton, B. L. (2012). Review the role of medial prefrontal cortex in memory and decision making. *Neuron*, *76*(6), 1057–1070. doi:10.1016/j.neuron.2012.12.002
- Farrar, M. J., & Goodman, G. S. (1992). Developmental changes in event memory. *Child Development*, *63*, 173–187. doi:10.2307/1130911
- Fellows, L. K. (2016). The neuroscience of human decision-making through the lens of learning and memory. In R. E. Clark & S. Martin (Eds.), *Behavioral neuroscience of learning and memory* (Vol. 37, pp. 231–251). Cham: Springer.
- Fernández, G., & Morris, R. G. M. (2018). Memory, novelty and prior knowledge. *Trends in Neurosciences*, *41*(10), 654–659. doi:10.1016/j.tins.2018.08.006
- Filomena, G., Verstegen, J. A., & Manley, E. A. (2019). A computational approach to 'The Image of the City'. *Cities*, *89*, 14–25. doi:10.1016/j.cities.2019.01.006
- Ghosh, V. E., & Gilboa, A. (2014). What is a memory schema? A historical perspective on current neuroscience literature. *Neuropsychologia*, *53*, 104–114. doi:10.1016/j.neuropsychologia.2013.11.010
- Gilboa, A., & Marlatte, H. (2017). Neurobiology of schemas and schema-mediated memory. *Trends in Cognitive Sciences*, *21*, 618–631. doi:10.1016/j.tics.2017.04.013
- Herdman, K. A., Calarco, N., Moscovitch, M., Hirshhorn, M., & Rosenbaum, R. S. (2015). Impoverished descriptions of familiar routes in three cases of hippocampal/medial temporal lobe amnesia. *Cortex*, *71*, 248–263. doi:10.1016/j.cortex.2015.06.008
- Kumaran, D. (2013). Schema-driven facilitation of new hierarchy learning in the transitive inference paradigm. *Learning & Memory*, *20*(7), 388–394. doi:10.1101/lm.030296.113
- Liu, Z.-X., Grady, C., & Moscovitch, M. (2016). Effects of prior knowledge on brain activation and connectivity during associative memory encoding. *Cerebral Cortex*, *27*, 1991–2009.
- Mandler, J. M. (1992). How to build a baby: II. Conceptual primitives. *Psychological Review*, *99*, 587–604. doi:10.1037/0033-295X.99.4.587
- Marchette, S. A., Ryan, J., & Epstein, R. A. (2017). Schematic representations of local environmental space guide goal-directed navigation. *Cognition*, *158*, 68–80. doi:10.1016/j.cognition.2016.10.005
- McKenzie, S., Robinson, N. T., Herrera, L., Churchill, J. C., & Eichenbaum, H. (2013). Learning causes reorganization of neuronal firing patterns to represent related experiences within a hippocampal schema. *Journal of Neuroscience*, *33*, 10243–10256. doi:10.1523/JNEUROSCI.0879-13.2013
- Piaget, J. (1954). *The construction of reality in the child*. New York: Basic.
- Preston, A. R., & Eichenbaum, H. (2013). Interplay of hippocampus and prefrontal cortex in memory. *Current Biology*, *23*, R764–R773. doi:10.1016/j.cub.2013.05.041
- Price, D. W. W., & Goodman, G. S. (1990). Visiting the wizard: Children's memory for a recurring event. *Child Development*, *61*, 664–680. doi:10.2307/1130952
- Pudhivadath, A., Roome, H. E., Coughlin, C., Nguyen, K. V., & Preston, A. R. (2019). Developmental differences in temporal schema acquisition impact reasoning decisions. *Cognitive Neuropsychology*. doi:10.1080/02643294.2019.1667316
- Raykov, P. P., Keidel, J. L., Oakhill, J., & Bird, C. M. (2019). The brain regions supporting schema-related processing of people's identities. *Cognitive Neuropsychology*. doi:10.1080/02643294.2019.1685958
- Ries, M. L., McLaren, D. G., Bendlin, B. B., Xu, G., Rowley, H. A., Birn, R., ... Johnson, S. C. (2012). Medial prefrontal functional connectivity: Relation to memory self-appraisal accuracy in older adults with and without memory disorders. *Neuropsychologia*, *50*, 603–611. doi:10.1016/j.neuropsychologia.2011.12.014
- Rini, R. (2019). Deepfakes and the epistemic backstop. *PhilArchive*.
- Robin, J., & Moscovitch, M. (2017). Details, gist and schema: Hippocampal-neocortical interactions underlying recent and remote episodic and spatial memory. *Current Opinion in Behavioral Sciences*, *17*, 114–123. doi:10.1016/j.cobeha.2017.07.016 doi:10.1016/j.cobeha.2017.07.016
- Roediger, H. L., & McDermott, K. B. (1995). Creating false memories: Remembering words not presented in lists. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *21*, 803–814. doi:10.1037/0278-7393.21.4.803
- Ryan, J. D., Kacollja, A., D'Angelo, M. C., Newsome, R. N., Gardner, S., & Rosenbaum, R. S. (2019). Existing semantic knowledge provides a schematic scaffold for inference in early cognitive decline, but not in amnesic MCI. *Cognitive Neuropsychology*. doi:10.1080/02643294.2019.1684886
- Tse, D., Langston, R. F., Kakeyama, M., Bethus, I., Spooner, P. A., Wood, E. R., ... Morris, R. G. M. (2007). Schemas and memory consolidation. *Science*, *316*(5821), 76–82. doi:10.1126/science.1135935 doi:10.1126/science.1135935
- van Kesteren, M. T. R., Beul, S. F., Takashima, A., Henson, R. N., Ruiter, D. J., & Fernández, G. (2013). Differential roles for medial prefrontal and medial temporal cortices in schema-dependent encoding: From congruent to incongruent. *Neuropsychologia*, *51*(12), 2352–2359. doi:10.1016/j.neuropsychologia.2013.05.027
- van Kesteren, M. T. R., Brown, T. I., & Wagner, A. D. (2018). Learned spatial schemas and prospective hippocampal

- activity support navigation after one-shot learning. *Frontiers in Human Neuroscience*, *12*, 486. doi:10.3389/fnhum.2018.00486
- van Kesteren, M. T. R., Ruitter, D. J., Fernández, G., & Henson, R. N. (2012). How schema and novelty augment memory formation. *Trends in Neurosciences*, *35*(4), 211–219. doi:10.1016/j.tins.2012.02.001
- Vosoughi, S., Roy, D., & Aral, S. (2018). The spread of true and false news online. *Science*, *359*, 1146–1152. doi:10.1126/science.aap9559
- Webb, C. E., & Dennis, N. A. (2019). Memory for the usual: The influence of schemas on memory for non-schematic information in younger and older adults. *Cognitive Neuropsychology*. doi:10.1080/02643294.2019.1674798
- Winocur, G., Moscovitch, M., Rosenbaum, R. S., & Sekeres, M. (2010). An investigation of the effects of hippocampal lesions in rats on pre- and post-operatively acquired spatial memory in a complex environment. *Hippocampus*, *20*, 1350–1365. doi:10.1002/hipo.20721
- Yu, L. Q., Kan, I. P., & Kable, J. W. (2019). Beyond a rod through the skull: A systematic review of lesion studies of the human ventromedial frontal lobe. *Cognitive Neuropsychology*. doi:10.1080/02643294.2019.1690981
- Zeithamova, D., Dominick, A. L., & Preston, A. R. (2012). Hippocampal and ventral medial prefrontal activation during retrieval-mediated learning supports novel inference. *Neuron*, *75*, 168–179. doi:10.1016/j.neuron.2012.05.010
- Zhang, W., Johndro, H., Budson, A. E., & Gutchess, A. (2019). Influence of self-referential mode on memory for aMCI patients. *Cognitive Neuropsychology*. doi:10.1080/02643294.2019.1657390