This is the accepted manuscript for an article due to be published in Current Directions in Psychological Science, publication details forthcoming

O'Connor, R & Riggs, K. (2019) Adult "fast mapping" memory research has misinterpreted developmental word learning data, CDIPS. DOI:

Corresponding author:

Richard O'Connor

Psychology Department

University of Hull

Cottingham Road

Hull, U.K.

Richard.OConnor@hull.ac.uk

Tel: +44 (0)1482 466718

Word count (abstract + main text): 2522

Adult “fast mapping” memory research has misinterpreted developmental word learning data

Richard O’Connor[1] & Kevin Riggs

Psychology Department,

University of Hull,

United Kingdom

Abstract

‘Fast mapping’ is often used to refer to children’s remarkable ability to learn the meanings of new words under minimal exposure conditions, in ambiguous contexts. While it is one thing to claim that children are capable of learning words this way, it is another to claim that this ability relies on a specific fast mapping neurocognitive mechanism that is critical for early word learning. Yet that claim has recently been made in adult memory research, and has been used as a theoretical justification for research into an adult fast mapping mechanism. In this review, we explain why the existence of such a mechanism in children is not supported by developmental research and explore the implications for adult fast mapping data and research.

Key words: Word learning, Fast mapping, Hippocampus

Adult memory research and “fast mapping”: assumptions regarding developmental research

In everyday conversation, it is not uncommon for adults to be ambiguously exposed to new words that they have to work out and remember the meanings of for themselves. Imagine you hear for the first time a friend say “My Huawei is great” while holding both a cup of coffee and a new piece of technology. We can easily infer that they are talking about their new phone, and we are able to remember this new word upon hearing it only once or twice. Indeed, in a seminal study, Carey and Bartlett (1978) found that 3-year-old children are capable of doing this too. They exposed children to an unknown colour word on a single occasion, and tested their retention of this novel word 7-10 days later. Just under half the children could identify the novel colour a week later, and the authors called this capability “fast mapping”.

In such scenarios, children must first make an inference as to the meaning (or referent) of the novel word. That initial process of referent selection has itself been called “fast mapping” (e.g., Horst, McMurray & Samuelson, 2006; Horst & Samuelson, 2008), and has been contrasted with children’s capability to retain and consolidate word-referent mappings across an extended period (i.e., word learning). As noted by Horst and colleagues, those two processes are logically independent. That said, a number of developmental researchers have used fast mapping to describe *both* initial disambiguation of the meaning of a novel word, and long term retention of that novel word (often days or weeks) despite having only been exposed to it a minimal number of times (e.g., Carey & Bartlett, 1978; Markson & Bloom, 1997; see also Swingley, 2010; Carey, 2010).

The idea that children learn new words following such minimal learning conditions has recently prompted memory researchers to investigate word learning in adults under similar conditions. In fast mapping (FM) learning conditions, adults are introduced to novel words *a minimal number of times in contexts that require disambiguation of their meaning* (e.g., Sharon, Moscovitch & Gilboa, 2011; for a recent review see Cooper, Greve & Henson, 2018). Moreover, several adult memory researchers have interpreted the developmental data to show these *specific learning conditions* engage a fast mapping neurocognitive mechanism, which critically supports word learning in children at an age whose hippocampus, a structure typically critical for human memory, is functionally immature (e.g., Sharon et al., 2011; Merhav, Karni & Gilboa, 2015; Atir-Sharon, Gilboa, Hazan, Koilis & Manevitz, 2015; Himmer, Muller, Gais & Schonauer, 2017).

By using FM conditions to tap into a purported developmental FM mechanism, it has been argued that adult word learning studies reveal evidence for a special form of learning that is rapid and independent of the hippocampus (e.g., Sharon, Moscovitch & Gilboa, 2011; Coutanche & Thompson-Schill, 2014; Merhav et al., 2015; Himmer et al., 2017). For example, Sharon et al. (2011) reported that patients with hippocampal damage are able to remember new words exposed under FM learning conditions, but not new words exposed under explicit encoding (EE) learning conditions, in which objects were explicitly labelled and participants instructed to remember them. Such data is interesting because models of declarative memory propose that learning such information involves a slow process of consolidation, in which memories are first dependent upon the hippocampus, and then over an extended period of time become hippocampus-independent (e.g., McClelland, McNaghton & O'Reilly, 1995). These models explain the difficulties hippocampal patients have with learning new information from EE learning conditions. The claim that a special form of hippocampus-independent learning exists, supporting both developmental and adult word learning following FM learning conditions, has therefore attracted considerable attention (Cooper et al., 2018).

We would argue, however, that such a claim misinterprets developmental word learning and memory research. It is one thing to suggest that children, of a certain age, are *capable* of learning new words from ambiguous contexts with minimal exposure. Yet it is another thing entirely to claim that word learning is *dependent* upon a specific neurocognitive mechanism, triggered by specific FM learning conditions. According to this latter view, one ought to predict that children learn words under FM learning conditions at an age *prior* to functional development of the hippocampus. Furthermore, if fast mapping learning conditions give rise to a specific form of hippocampus-independent learning, then one ought to predict that children, in whom the hippocampus is still developing, would show better retention under these conditions compared to those that are purportedly hippocampus-dependent, such as explicit instruction. After all, it was this logic that prompted researchers to compare retention after FM and EE conditions in adult populations with known hippocampal abnormalities (e.g., Sharon et al., 2011; Korenic, Nisonger, Krause, Wijtenburg, Elliot Hong & Rowland, 2016).

As we explain below though, there is no developmental evidence supporting either of these predictions. The existence of a critical FM mechanism in children - hippocampus independent, giving rise to long-term retention under minimal exposure conditions - is not supported by developmental research. Recognising this misinterpretation is important for adult memory researchers. If one erroneously believes in the existence of a developmental FM neurocognitive mechanism to predict and explain adult data, then important research questions, such as establishing which specific features of FM learning conditions actually affect word learning, are at risk of not being addressed.

<u>FM learning conditions do not promote learning in children prior to functional hippocampus development</u>

Understanding the age at which children show evidence of word learning after exposure to novel words in FM learning conditions is critical for understanding how some adult memory researchers have misinterpreted the developmental data. There is evidence that from 17 months toddlers can disambiguate the referent of a novel word, for example, by looking more at a novel object in preference to a familiar object upon hearing a novel word (e.g., Halberda, 2003; cf. Markman, 1990). However, such "fast mapping" studies do not test retention of the novel word. The few studies reporting memory after a delay for new object-word pairings in infants and toddlers do *not* use FM learning conditions: they make use of multiple repetitions of the word-object mappings or provide unambiguous word-object pairings (e.g., Woodward, Markman & Fitzsimmons, 1994; Houston-Price, Plunkett & Harris, 2005). These are very different from the FM learning conditions used by adult memory researchers, with minimal exposure and disambiguation of word meaning.

As first noted by Horst and colleagues, there is very little evidence that young children do learn new words under FM learning conditions (Horst et al., 2006; Horst & Samuelson, 2008). In fact, several studies show that 18- to 24-month-old children *fail* to learn word meanings from FM conditions, even after only a 5-minute delay (e.g., Horst & Samuelson, 2008; Bion, Borovskey & Fernald, 2013; Kucker, McMurray, Samuelson, 2018). Where memory has been shown in 2-year-old children following FM conditions, memory has been tested almost immediately after the learning trials (e.g., Spiegel & Halberda, 2011; Bion et al., 2013). As noted by Horst & Samuelson (2008), it is not clear whether such immediate memory performance measures word learning, or simply repetition of a recent previous selection.

The FM studies that have used more significant delays (e.g., 24 hours or more) typically only show retention in children above 3-years-old (e.g., Carey & Bartlett, 1978; Markson & Bloom, 1997; Vlach & Sandhofer, 2012; Holland, Simpson & Riggs, 2015; Holland, Hyde, Simpson & Riggs, 2018). Furthermore, such studies only introduce children to a single novel word. Some researchers have questioned whether this is a robust test of word learning – at test, children could merely be remembering which object had been previously singled out with a label (e.g., Schafer & Plunkett, 1998). Indeed, Axelsson & Horst (2013) have found that 2-year-olds fail to show even immediate retention of novel words following fast mapping of more than one novel word. Recent data, however, suggests that 2.5-year-olds can show some retention 24 hours after fast mapping 4 novel words, but *only* if they nap immediately after learning (Axelsson, Swinton, Winiger & Horst, 2018).

It is important to note that outside of word learning children begin to show long-term memory on tasks believed to be dependent upon hippocampal function by the end of their *second year*. For example, 20-month-olds show delayed recall of a temporal sequence following a single exposure (Bauer & Leventon, 2013), a task typically failed by patients with hippocampal damage (McDonough, Mandler, MeKee & Squire, 1995). The hippocampus may not have reached full functional maturity at 2-years-old, but there is evidence that it is can support declarative memory by this age (for reviews see Bauer, 2013; Gomez & Edgin, 2016). Thus where 2.5- and 3-year-old children have shown memory after a significant delay following FM conditions, this is not evidence for a non-hippocampal learning mechanism, as suggested by some adult memory researchers. Indeed, it is conceivable that functional development of the hippocampus *supports* the emergence of long-term retention. That would be consistent with the sensitivity of such retention to whether children nap immediately following learning (Axelsson et al., 2018), given the role that sleep has been proposed to play in hippocampus-mediated memory consolidation (e.g., Gais & Born, 2004; Davis & Gaskell, 2009; c.f. Himmer et al., 2017).

<u>FM learning conditions are not beneficial for word learning</u>

As we have seen, only children from 3 years of age consistently show evidence of word learning following FM learning conditions. Furthermore, even when retention is seen, FM conditions do not provide any special word learning benefit over other learning conditions. Where children's retention under FM conditions has been directly compared with conditions explicitly giving the word-object mappings, there is *no evidence* that FM conditions specifically help children to learn those words (Jaswal & Markman, 2003; Zosh, Brinster & Halberda, 2013)[2]. Indeed, even in studies with developmental populations associated with compromised hippocampus functions (e.g., Down's Syndrome), FM conditions do not give rise to better learning than explicit instruction (Sakhon, Edwards, Luongo, Murphy & Edgin, 2018).

In fact, in studies that make the association between word and object more explicit by introducing additional cues during fast mapping, long-term retention has been found to *improve* in children (e.g., Vlach & Sandhofer, 2012). Furthermore, long-term retention in FM studies is typically only found when children learn specific types of words, such as count nouns. FM conditions do not readily support the long-term learning of colour, shape and texture words (Holland et al., 2015), thus limiting the conceived usefulness of any purported FM mechanism for children's word learning. It may be the case that in certain circumstances, and upon reaching a certain age, children are able to learn from FM conditions. However, this does not imply that these conditions therefore engage a specific neurocognitive mechanism that is both conducive and critical for word learning, contrary to the claims of some researchers (e.g., Merhav et al., 2015; Altir-Sharon et al., 2015).

What does this mean for adult memory researchers?

Addressing misinterpretations of developmental data is important for researchers investigating adult memory, because it was exactly those misinterpretations that informed the original theoretical justification for using FM learning conditions in their research (Sharon et al., 2011). Once it is recognised that a key justification for expecting FM conditions to produce hippocampus-independent learning in adults was based on a misinterpretation, it is perhaps not surprising that there is conflicting evidence and considerable debate in this regard (see Cooper et al., 2018). For example, while two early studies reported that patients with damage to the hippocampus learn new words under FM, but not EE conditions (Sharon et al., 2011; Merhav, Karni & Gilboa, 2014), this finding has not been readily replicated with similar patient groups (Smith, Urgolites, Hopkins & Squire, 2014; Warren & Duff, 2014; Warren, Tranel & Duff, 2016). Further, a number of studies with participant populations associated with compromised hippocampal function have failed to find any difference in word learning between EE and FM conditions relative to controls (Greve, Cooper & Henson, 2014; Korenic et al., 2016; Sakhon et al., 2018). Finally, brain-imaging studies with healthy adults have found the hippocampus to be active during both FM encoding and retrieval (Atir-Sharon et al., 2015; Merhav et al., 2015). The developmental data discussed in this review add to this body of evidence speaking against the claim that FM conditions support any special form of hippocampus-independent learning.

Furthermore, by rejecting the idea that the learning conditions in FM studies engage a specific neurocognitive mechanism we hope to encourage a more systematic focus on how different encoding contexts affect word learning. Clearly, children and adults do encounter situations in which they incidentally hear a new word and have to work out its meaning. Within laboratory-based tasks that attempt to reproduce such situations, FM conditions differ from EE conditions in several respects (e.g., the presence or not of familiar objects; different task instructions), each of which might affect word learning. While in the developmental literature a number of studies have attempted to manipulate factors within FM conditions to assess their effects on memory (e.g., Vlach & Sandhofer, 2012; Axelsson & Horst, 2014), relatively few studies with adults have done so (for recent exceptions, see Coutanche & Thompson-Schill, 2014; Coutanche & Koch, 2017; Cooper, Greve & Henson, 2019). Beyond a consistent finding that *healthy* adults remember more from EE conditions, there do appear to be some additional differences in memory performance between FM and EE conditions, such as in susceptibility to catastrophic interference or the extent to which novel words are integrated into the lexicon (e.g., Merhav et al., 2014; Coutanche & Thompson-Schill, 2014; Coutanche & Koch, 2017; see Cooper et al., 2018). Convincing explanations for these latter differences in learning between FM and EE conditions will only result from (a) robust replication of these effects and (b) systematic investigation of those specific features of FM that cause such effects (for similar arguments see Cooper et al., 2018, 2019).

To conclude, we have argued that developmental research does not support the claim that FM conditions trigger in children a neurocognitive mechanism, critical for word learning. Specifically, there is no evidence of hippocampus-independent retention following FM conditions, given the age at which children show evidence of long-term retention, and there is no evidence that children learn differently under those conditions than under explicit instruction. By highlighting this misconception, we hope this review will inform the thinking of future researchers interested in memory and word learning across the lifespan.

Endnotes

[1] Address correspondence to Dr Richard O'Connor, Psychology Department, University of Hull, United Kingdom.

[2] While Zosh et al. (2013) suggest in their paper that there is a difference between their FM and EE conditions (respectively called "inference" and "instruction" in the paper), they do not report a direct statistical test of the significance of that difference. When one directly compares the proportions of children showing memory following each condition (Exp. 1, FM = 13/24; EE = 7/24: Exp 2, FM = 8 / 12; EE = 5 / 12), there is no significant statistical difference between the two conditions in either experiment.

References

Atir-Sharon, T., Gilboa, A., Hazan, H., Koilis, E., & Manevitz, L. M. (2015). Decoding the formation of new semantics: MVPA investigation of rapid neocortical plasticity during associative encoding through Fast Mapping. *Neural plasticity*, *2015*.

Axelsson, E. L., & Horst, J. S. (2013). Testing a word is not a test of word learning. *Acta Psychologica*, *144*(2), 264-268.

Axelsson, E. L., & Horst, J. S. (2014). Contextual repetition facilitates word learning via fast mapping. *Acta Psychologica*, *152*, 95-99.

Axelsson, E. L., Swinton, J., Winiger, A. I., & Horst, J. S. (2018). Napping and toddlers' memory for fast-mapped words. *First Language*, *38*(6), 582-595.

Bauer, P. J. (2013). Memory. In P. D. Zelazo (Ed.), *Oxford handbook of developmental psychology* (Vol. 1, pp. 505–541). New York, NY: Oxford University Press.

Bauer, P. J., & Leventon, J. S. (2013). Memory for one-time experiences in the second year of life: Implications for the status of episodic memory. *Infancy*, *18*(5), 755-781.

Bion, R. A., Borovsky, A., & Fernald, A. (2013). Fast mapping, slow learning: Disambiguation of novel word–object mappings in relation to vocabulary learning at 18, 24, and 30 months. *Cognition*, *126*(1), 39-53.

Carey, S. (2010). Beyond fast mapping. *Language Learning and Development*, *6*(3), 184-205.

Carey, S., & Bartlett, E. (1978). Acquiring a single new word. *Proceedings of the Stanford Child Language Conference, 15*, 17–29.

Cooper, E., Greve, A., & Henson, R. N. (2018). Little evidence for Fast Mapping (FM) in adults: A review and discussion. *Cognitive Neuroscience*, 1-14.

Cooper, E., Greve, A., & Henson, R. N. (2019). Investigating Fast Mapping task components: no evidence for the role of semantic referent nor semantic inference in healthy adults. *Frontiers in Psychology*. doi: 10.3389/fpsyg.2019.00394

Coutanche, M. N., & Koch, G. E. (2017). Variation across individuals and items determine learning outcomes from fast mapping. *Neuropsychologia*, *106*, 187-193.

Coutanche, M. N., & Thompson-Schill, S. L. (2014). Fast mapping rapidly integrates information into existing memory networks. *Journal of Experimental Psychology: General*, *143*(6), 2296.

Davis, M. H., & Gaskell, M. G. (2009). A complementary systems account of word learning: neural and behavioural evidence. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*(1536), 3773-3800.

Gais, S., & Born, J. (2004). Declarative memory consolidation: mechanisms acting during human sleep. *Learning & Memory*, *11*(6), 679-685.

Gómez, R. L., & Edgin, J. O. (2016). The extended trajectory of hippocampal development: Implications for early memory development and disorder. *Developmental cognitive neuroscience*, *18*, 57-69.

Greve, A., Cooper, E., & Henson, R. N. (2014). No evidence that 'fast-mapping'benefits novel learning in healthy older adults. *Neuropsychologia*, *60*, 52-59.

Halberda, J. (2003). The development of a word-learning strategy. *Cognition*, *87*(1), B23-B34.

Himmer, L., Müller, E., Gais, S., & Schönauer, M. (2017). Sleep-mediated memory consolidation depends on the level of integration at encoding. *Neurobiology of learning and memory*, *137*, 101-106.

Holland, A. K., Hyde, G., Riggs, K. J., & Simpson, A. (2018). Preschoolers fast map and retain artifact functions as efficiently as artifact names, but artifact actions are the most easily learned. *Journal of experimental child psychology*, *170*, 57-71.

Holland, A., Simpson, A., & Riggs, K. J. (2015). Young children retain fast mapped object labels better than shape, color, and texture words. *Journal of experimental child psychology*, *134*, 1-11.

Horst, J.S., McMurray, B., & Samuelson, L.K. (2006). Online processing is essential for learning: understanding fast mapping and word learning in a dynamic connectionist architecture. *Proceedings of the 28th Meeting of the Cognitive Science Society*, 339–344.

Horst, J. S., & Samuelson, L. K. (2008). Fast mapping but poor retention by 24-month-old infants. *Infancy*, *13*(2), 128-157.

Houston-Price, C., Plunkett, K. I. M., & Harris, P. (2005). 'Word-learning wizardry'at 1; 6. *Journal of Child Language*, *32*(1), 175-189.

Jaswal, V. K., & Markman, E. M. (2003). The relative strengths of indirect and direct word learning. *Developmental Psychology*, *39*(4), 745.

Korenic, S. A., Nisonger, S. J., Krause, B. W., Wijtenburg, S. A., Hong, L. E., & Rowland, L. M. (2016). Effectiveness of fast mapping to promote learning in schizophrenia. *Schizophrenia Research: Cognition*, *4*, 24-31.

Kucker, S. C., McMurray, B., & Samuelson, L. K. (2018). Too Much of a Good Thing: How Novelty Biases and Vocabulary Influence Known and Novel Referent Selection in 18-Month-Old Children and Associative Learning Models. *Cognitive science*, *42*, 463-493.

Markman, E. M. (1990). Constraints children place on word meanings. *Cognitive science*, *14*(1), 57-77.

Markson, L., & Bloom, P. (1997). Evidence against a dedicated system for word learning in children. *Nature*, *385*, 813–815.

McClelland, J. L., McNaughton, B. L., & O'reilly, R. C. (1995). Why there are complementary learning systems in the hippocampus and neocortex: insights from the successes and failures of connectionist models of learning and memory. *Psychological review*, *102*(3), 419.

McDonough, L., Mandler, J. M., McKee, R. D., & Squire, L. R. (1995). The deferred imitation task as a nonverbal measure of declarative memory. *Proceedings of the National Academy of Sciences*, *92*(16), 7580-7584.

Merhav, M., Karni, A., & Gilboa, A. (2014). Neocortical catastrophic interference in healthy and amnesic adults: a paradoxical matter of time. *Hippocampus*, *24*(12), 1653-1662.

Merhav, M., Karni, A., & Gilboa, A. (2015). Not all declarative memories are created equal: fast mapping as a direct route to cortical declarative representations. *Neuroimage*, *117*, 80-92.

Sakhon, S., Edwards, K., Luongo, A., Murphy, M., & Edgin, J. (2018). Small Sets of Novel Words Are Fully Retained After 1-Week in Typically Developing Children and Down Syndrome: A Fast Mapping Study. *Journal of the International Neuropsychological Society*, *24*(9), 955-965.

Schafer, G., & Plunkett, K. (1998). Rapid word learning by fifteen-month-olds under tightly controlled conditions. *Child Development*, *69*(2), 309-320.

Sharon, T., Moscovitch, M., & Gilboa, A. (2011). Rapid neocortical acquisition of long-term arbitrary associations independent of the hippocampus. *Proceedings of the National Academy of Sciences*, *108*(3), 1146-1151.

Smith, C. N., Urgolites, Z. J., Hopkins, R. O., & Squire, L. R. (2014). Comparison of explicit and incidental learning strategies in memory-impaired patients. *Proceedings of the National Academy of Sciences*, *111*(1), 475-479.

Spiegel, C., & Halberda, J. (2011). Rapid fast-mapping abilities in 2-year-olds. *Journal of experimental child psychology*, *109*(1), 132-140.

Swingley, D. (2010). Fast mapping and slow mapping in children's word learning. *Language learning and Development*, *6*(3), 179-183.

Vlach, H., & Sandhofer, C. M. (2012). Fast mapping across time: memory processes support children’s retention of learned words. *Frontiers in psychology*, *3*, 46.

Warren, D. E., & Duff, M. C. (2014). Not so fast: Hippocampal amnesia slows word learning despite successful fast mapping. *Hippocampus*, *24*(8), 920-933.

Warren, D. E., Tranel, D., & Duff, M. C. (2016). Impaired acquisition of new words after left temporal lobectomy despite normal fast-mapping behavior. *Neuropsychologia*, *80*, 165-175.

Woodward, A. L., Markman, E. M., & Fitzsimmons, C. M. (1994). Rapid word learning in 13-and 18-month-olds. *Developmental psychology*, *30*(4), 553.

Zosh, J. M., Brinster, M., & Halberda, J. (2013). Optimal contrast: Competition between two referents improves word learning. *Applied Developmental Science*, *17*(1), 20-28.

Recommended readings

1) Sharon, T., Moscovitch, M., & Gilboa, A. (2011). See reference list.

   The original adult memory research paper to make claims about fast mapping in children as a 'neurocognitive mechanism' and apply a fast mapping paradigm to adult amnesic patients.

2) Coutanche, M. N., & Thompson-Schill, S. L. (2015). Rapid consolidation of new knowledge in adulthood via fast mapping. *Trends in cognitive sciences*, *19*(9), 486-488.

   A review and discussion of adult fast mapping research from researchers interested in adult memory and word learning.

3) Cooper, E., Greve, A., & Henson, R. N. (2018). See reference list.

   A more recent critical review and discussion of adult fast mapping research.

4) Gómez, R. L., & Edgin, J. O. (2016). See reference list.

   A review of the development of children's performance on hippocampus-dependent memory tasks.

5) Holland, A., Simpson, A., & Riggs, K. J. (2015). See reference list.

   A representative study illustrating recent developmental fast mapping research, introduction contains a review of developmental research on long-term retention of words following fast mapping.