Something old, something new: A review of the literature on sleep-related lexicalization of novel words in adults

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Abstract

Word learning is a crucial aspect of human development that depends on the formation and consolidation of novel memory traces. In this paper, we critically review the behavioural research on sleep-related lexicalization of novel words in healthy young adult speakers. We first describe human memory systems, the processes underlying memory consolidation, then we describe the complementary learning systems account of memory consolidation. We then review behavioural studies focusing on novel word learning and sleep-related lexicalization in monolingual samples, while highlighting their relevance to three main theoretical questions. Finally, we review the few studies that have investigated sleep-related lexicalization in L2 speakers. Overall, while several studies suggest that sleep promotes the gradual transformation of initially labile traces into more stable representations, a growing body of work suggests a rich variety of time courses for novel word lexicalization. Moreover, there is a need for more work on sleep-related lexicalization patterns in varied populations, such as L2 speakers and bilingual speakers, and more work on individual differences, to fully understand the boundary conditions of this phenomenon.

Keywords Novel words · Systems consolidation · Lexicalization · Sleep · Episodic memory · Semantic memory

“...Ὡρη μὲν πολέων μύθων, ὥρη δὲ καὶ ὕπνου.”
(Homer, *The Odyssey*, XI, 379)
 (“... there is a time for many words and there is a time also for sleep.” [Translation A. T. Murray, 1927, p. 413])

People add words (i.e., vocabulary) to their mental lexicon throughout their lives. Of relevance here, a large majority of new vocabulary is acquired after early childhood and throughout adulthood (Anglin, 1993; Carlisle & Katz, 2006), and a rich lexicon predicts academic achievement in both children (e.g., Fernald, Marchman, & Weisleder, 2013) and adults (e.g.,

Treffers-Daller & Milton, 2013). It is therefore crucial to understand how people learn novel words throughout adulthood.

To facilitate this understanding, here we review the research on sleep-related lexicalization of novel words in healthy young adult speakers. Because a substantial amount of work has been published in the domain, we focus this review on behavioural studies, thus excluding for the time being many fascinating studies of brain dynamics during sleep (through electroencephalography) or during testing (through functional MRI). Our ultimate goal is to arrive at consensus about what is currently known about these processes, and also what avenues of future research might be valuable.

In what follows, we first describe the processes underlying memory consolidation, and describe an influential model of memory consolidation (the complementary learning systems account, M. H. Davis & Gaskell, 2009; McClelland, 2013; McClelland, McNaughton, & O'Reilly, 1995; Norman & O'Reilly, 2003; O'Reilly & Rudy, 2000). We then review the studies focusing on novel word learning and sleep-related lexicalization in monolingual/native speakers samples.¹ We review

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¹ It is important to emphasize that most of the studies reviewed omit information such as whether participants knew other languages than their native language, or whether knowledge of multiple languages was assessed. One can assume that these participants were monolingual, but the results should nevertheless be considered carefully.

studies in a theoretically-driven fashion, by evaluating how consistent these are with regards to three key points of the CLS account. We also review the few studies on novel word learning and lexicalization in second language learner samples.

Human memory and novel word learning

While some have argued that linguistic knowledge and processes are architecturally distinct from general cognition (e.g., Adger, 2017; Fodor, 1983), we see language as one of many highly overlearned and automatized forms of knowledge that are subject to general constraints of the human memory system. This view of language is highly compatible with recent theoretical accounts within psycholinguistics and natural language understanding that fall under the collective umbrella of usage-based models (e.g., Bates & MacWhinney, 1989; Goldberg, 2006; Tomasello, 2003). Consequently, we postulate that the study of language is important in its own right, and also in serving as a tool with which to better understand human memory generally. Accordingly, learning novel words primarily depends on the long-term storage and on the updating of our lexical representations. To understand the relationship between word learning and memory, we first briefly describe the organization of human memory, then the various memory consolidation models, and we will discuss the complex role of sleep in memory formation.

Human memory is traditionally divided into declarative memory and nondeclarative memory (Squire & Zola, 1996). Declarative memory includes all consciously accessible memories, from personal memories of our past (episodic memory) to general knowledge of facts (semantic memory; Tulving, 1985). Nondeclarative memory, in contrast, includes nonconscious memories for actions, skills, and implicitly learned content (procedural memory). However, complex cognitive abilities, such as language, involve the recruitment of both declarative and nondeclarative memory. For example, producing a voiced fricative (e.g., /z/, as in “buzz”) relies on procedural knowledge, while learning the novel word “synapse” relies on declarative knowledge. In this review, we focus particularly on the consolidation of declarative memories for novel words.

Consolidation has been traditionally defined as hypothesized process by which memories go from a labile state to a stable state as time passes. It has been the topic of much research over the past century. From early research on retrograde amnesia (e.g., Ribot, 1881; Scoville & Milner, 1957) to recent discoveries in the field of optogenetics (e.g., Kitamura et al., 2017), two different—albeit likely related—consolidation processes have been identified. *Synaptic (or cellular) consolidation* describes the synaptic plasticity associated with a learning episode, while *systems consolidation* refers to the reorganization of brain systems supporting memories (see Squire, Genzel, Wixted, & Morris, 2015). Here, we

are specifically interested in the latter. In what follows, we describe an influential model of human declarative memory—the complementary learning system model (henceforth, CLS model; McClelland et al., 1995; Norman & O'Reilly, 2003; O'Reilly & Rudy, 2000). In this model, “consolidation” is more than the stabilization of a memory trace—it entails processes related to the abstraction of common features beyond the learning situation. Memories are not simply transferred or copied; they are crucially transformed.

The CLS model proposes that learning is supported by two distinct memory systems, referred to as the hippocampal and neocortical systems. Accordingly, while memory traces are initially formed in both the hippocampus and the neocortex, memory initially depends on synaptic plasticity in the hippocampus. With respect to novel word learning (M. H. Davis & Gaskell, 2009), this means that memories for novel words are initially encoded in episodic memory, which is dependent on the hippocampus and medio-temporal lobe systems. This system is thought to encode novel experience immediately by a sparse pattern of activity, leading to independent, nonoverlapping representations (e.g., Winocur, Sekeres, Binns, & Moscovitch, 2013; Yassa & Stark, 2011). However, over time, novel words may become generalized beyond the specific context in which they were learned, thus becoming stable semantic representations (M. H. Davis & Gaskell, 2009). Semantic memory can therefore be thought of as a “mental thesaurus,” crucial to the use of language (Tulving, 1972, p. 386).² Semantic representations for novel words are thought to depend on the neocortex (e.g., superior temporal gyrus), which stores overlapping, distributed representations. Hippocampal memory representations and neocortical memory representations are therefore different in nature (episodic vs. semantic, respectively).

Crucially, novel word lexicalization is possible because the hippocampus plays a central role in indexing and coordinating developing neocortical traces, which fosters the emergence of distributed and interconnected neocortical networks. The development of these networks is thought to occur during periods of off-line consolidation, such as rehearsal, reminiscence, or sleep. One of the CLS account's predictions is that off-line consolidation plays a crucial role in the emergence of neocortical representations for novel words, in that it allows novel words to become interleaved with existing lexical representations in the mental lexicon of an individual. Sleep is an ideal state for this interleaving to occur, because the cognitive system is not actively processing novel information

² Of note, Davis and Gaskell (2009) use the term *semantic representations* interchangeably to describe (a) representations related to the semantics of a word (i.e., its meaning) and (b) consolidated representations that have been generalized beyond the context in which they were learned (i.e., that are part of semantic memory). Importantly, representations that are part of semantic memory are not necessarily related to word meaning, as other features of a word (e.g., its orthography) can also become part of semantic memory.

(McClelland et al., 1995). Specifically, hippocampal representations are posited to be reactivated during slow-wave sleep and to prime related neocortical representations.³ Once long-term representations for novel words are established,⁴ reliance on hippocampal activity for memory retrieval is no longer crucial. The transition from hippocampus-dependence to hippocampus-independence is what can be described as systems consolidation—consolidated novel words become an integral part of the individual’s mental lexicon. It should be noted, however, that the CLS model predicts that the interleaving of novel knowledge with existing knowledge may occur during wake as a consequence of interleaved exposure to novel and existing knowledge (McClelland et al., 1995).

The CLS model is consistent with the observation that remote episodic memories are typically preserved in patients with hippocampal damage, while recent ones are impaired (e.g., Buchanan, Tranel, & Adolphs, 2005; Kirwan, Bayley, Galvan, & Squire, 2008). Interestingly, the initial formulation of the model described the hippocampus as a “fast” learning system and the neocortex as a “slow” learning system. This division of labor ensures that established memory representations are not disrupted by novel information (a process called “catastrophic interference”; see McClelland et al., 1995; McClosky & Cohen, 1989). Therefore, the CLS account predicts that novel words do not interact with existing words immediately, as they depend primarily on episodic memory, but do interact with existing words after an interval of sleep, once they have been consolidated into semantic memory. Once they have been consolidated into semantic memory, novel words are said to be lexicalized, and thus functioning as actual known words for the learner. This means that retrieval of existing words may be impacted by novel words, to the extent that these are represented in semantic memory. This distinction between episodic and semantic systems is supported by simulations in connectionist models (e.g., McClelland,

2013; McClelland et al., 1995) and by brain imaging data (e.g., M. H. Davis, Di Betta, MacDonald, & Gaskell, 2009).

To illustrate, when an existing word (e.g., *cathedral*) is presented to a participant, its activation may be impeded by lexicalized novel words (e.g. *cathedruce*), even though these novel words are not presented during the task (e.g., Gaskell & Dumay, 2003, reviewed below). This reflects competition between lexicalized orthographic representations. A related effect is form priming—novel words may show an effect known as a *prime lexicality effect* when they are used as masked primes to existing words (e.g., C. J. Davis & Lupker, 2006). Masked form priming effects crucially depend on the status of the prime. Nonword primes (e.g., *contrapt*—*CONTRACT*) have been shown to facilitate processing of orthographically related targets, whereas word primes (e.g., *contrast*—*CONTRACT*) do not (a *prime lexicality effect*; see C. J. Davis & Lupker, 2006). If novel words become lexicalized during an experiment, they should therefore not facilitate processing of orthographically related existing words.⁵

Finally, semantic priming effects may also arise once a novel word become lexicalized. Word primes that are semantically related to the target facilitate processing of this target (e.g., *cat*—*KITTEN*), an effect that is not observed in nonword primes (e.g., *feckton*—*KITTEN*; see McNamara, 2005, for a review). However, if novel words are associated with a meaning (e.g., *feckton*, “a cat with blueish grey stripes”) and become lexicalized during an experiment, they may become semantic primes for semantically related existing words (e.g., *feckton*—*KITTEN*).⁶

³ In more precise terms, the prefrontal cortex, during slow-wave sleep, drives slow oscillations to the medio-temporal lobe (e.g., Nir et al., 2011). This triggers neural replay of the learning episode in the hippocampus, evidenced in sharp wave ripple complexes (e.g., Euston, Tatsuno, & McNaughton, 2007). In turn, this neural replay triggers the potentiation of synaptic connections within the prefrontal cortex (e.g., Peyrache, Khamassi, Benchenane, Wiener, & Battaglia, 2009)—the neural firing pattern arising at the moment of learning is also replayed in the neocortex during sleep (e.g., Genzel et al., 2015; Sirota, Csicsvari, Buhl, & Buzsaki, 2003). Slow neocortical oscillations also trigger spindle oscillations in the thalamus, which synchronize hippocampal and neocortical activity (e.g., Latchoumane, Ngo, Born, & Shin, 2017)—a process crucial to the integration of novel knowledge into preexisting schemas, which correlates with reduced hippocampal recruitment at later time points (e.g., Hennies, Ralph, Kempkes, Cousins, & Lewis, 2016). It should be noted that the role of sleep in memory consolidation is still questioned (e.g., Nemeth, Gerbier, & Janacek, 2019; Yonelinas, Ranganath, Ekstrom, & Wiltgen, 2019). For literature reviews of the role of sleep in human memory, see Rasch and Born (2013) and Walker and Stickgold (2006).

⁴ Long-term memory should be understood here in the perspective of systems consolidation, for which the time scale is days to decades.

⁵ These effects are usually interpreted as reflecting activation spreading in semantic networks when input is encountered (interactive activation model; C. J. Davis & Lupker, 2006; McClelland & Rumelhart, 1981). Interconnectedness between units is the product of experience, in that the connection weight between words evolves with experience. Initially, novel representations are sparse and isolated from the semantic network, but once the connection weight between novel and older representations has reached a certain threshold, they start interacting (e.g., semantic priming, prediction of upcoming input). These effects are thought to be implicit and to reflect the interconnected nature of the mental lexicon. When a prime is a real word (e.g., *contrast*), this real word is activated in semantic memory. This prime generates lateral inhibition, that the orthographically related target word (e.g., *CONTRACT*) will have to overcome in order to be recognized—a consequence being that priming is nullified, or even negative. In contrast, a nonword prime (e.g., *contrapt*) is not associated with a representation in semantic memory, which means that the only lexical entry that matches the prime is the target (e.g., *CONTRACT*). Exposure to the novel word therefore builds up activation of the existing word, which temporarily strengthens the lexical representation of this existing word. There is no lateral inhibition of orthographically related target words taking place, and instead positive priming (i.e., facilitation) is evidenced. Absence of form priming can therefore be interpreted as the cancellation of positive form priming, and the hallmark of lexicalization.

⁶ Semantic priming arises from the same mechanism of activation spreading in semantic networks—when the prime word is encountered, its semantic representation spreads to semantically related representations, which facilitates the processing of related target words by preactivating them (McNamara, 2005). The presence of semantic priming can therefore be interpreted as a hallmark of lexicalization for novel words.

Finally, a more recent formulation of this model suggests that learning might actually depend on prior knowledge (McClelland, 2013). Prior knowledge, in the CLS model, is represented as *schemas*—networks of interconnected neocortical representations that impact information processing (van Kesteren, Ruiter, Fernandez, & Henson, 2012). Consistency with existing schemas is predicted to enhance the integration of new knowledge in memory networks.

Thus, novel words that are consistent with existing words in a known language may activate phonological/orthographical representations in the language (e.g., *cathedruce* may activate the word *cathedral*). Inconsistency—as in the case of novel words that do not resemble existing words—may slow down this process (see McClelland, 2013; McClelland, McNaughton, & Lampinen, 2020). This distinction is thought to prevent catastrophic interference. Crucially, the neocortex might be able to integrate novel knowledge faster if it is consistent with prior knowledge, whereas the hippocampus might handle information inconsistent with prior knowledge (McClelland, 2013; McClelland et al., 2020).

The time course of novel word learning and lexicalization in monolinguals/L1 speakers

Below, we review 28 behavioural studies of sleep-related novel word learning that share a similar core design (see Appendix A). In these studies, participants were trained on novel words. On a subsequent day (which means, after one or multiple sleep intervals), they were tested on their knowledge of these novel words. We review these studies in a theoretically driven way, rather than in chronological order, by structuring the review around three questions central to the CLS account: (1) Is there evidence of a dichotomy between episodic and lexicalized representations, and what is the nature of their relationship? (2) Is sleep crucial for novel word lexicalization, and if so, how? (3) What is the role of prior knowledge in the establishment of novel word representations? For Points 1 and 2, we further split the studies depending on their consistency with the prediction formulated by the CLS account. Note that many of the studies reviewed in a given section have relevance for other sections as well.

Is there evidence of a dichotomy between episodic and lexicalized representations, and what is the nature of their relationship? The CLS account posits a dichotomy between episodic memory and semantic memory, which are thought to depend on different brain structures (M. H. Davis & Gaskell, 2009). While episodic memories emerge immediately, the development of abstract, lexicalized representations within semantic memory is thought to be a gradual process. At this

point, newly lexicalized representations should interact with older lexicalized representations (i.e., existing words in a given language).

Studies consistent with the predictions. In one of the earliest studies on the topic, Gaskell and Dumay (2003) investigated novel word learning and its impact on the organization of the mental lexicon. In Experiment 2, the authors trained native English speakers on novel spoken words based on existing English words (e.g., *cathedral*). The novel words differed from their base words either in their initial syllable (e.g., *yothedral*) or in their final syllable (e.g., *cathedruce*). Importantly, the onset of *cathedruce* matches the onset of *cathedral*, which makes it a cohort competitor—a word that is activated automatically when the onset *cathedr-* is encountered (Marslen-Wilson, 1987). Participants were trained through a phoneme-monitoring task (e.g. “Is there an ‘e’ in *cathedruce*?”).⁷

The experiment spanned on 5 consecutive days and started with a lexical decision task to assess baseline reaction time to the base words on Day 1. During the lexical decision task, participants had to make timed lexical decisions to base words and intervening fillers (the fillers were either English words or nonwords). Participants were then trained on the novel words. On Day 2, they performed a second lexical decision task, then a forced-choice task to assess episodic recognition of the novel words compared with untrained novel words. After the lexical decision task, participants were trained again on the same novel words as on Day 1. On each subsequent day, the participants performed the same tasks and training, except on the final day (Day 5), during which they were not further trained.

Results in the forced-choice task indicated that episodic recognition of the novel words was generally high, with participants performing well above chance on novel words with initial and final deviation. In contrast, reaction times to the base words in the lexical decision task were slower for base words (e.g., *cathedral*), but only when the trained novel words were cohort competitors.⁸ This suggests that these novel words competed with base words for lexical access. Because this competition effect only emerged on Days 4 and 5, it suggests that novel words do not compete with existing words for lexical access immediately after training. Interestingly, Experiment 1 of Gaskell and Dumay (2003), which did not involve a sleep interval, suggests that novel words may even facilitate access to base words immediately after training.

This pattern of facilitation-competition can be explained by the lexicalization of the novel word. When no lexical entry is

⁷ Participants were instructed that they would hear unfamiliar words, and that while these were not real words, that they should treat them as if they were. Novel words were therefore presented as artificial.

⁸ The crucial interaction of type of competitor and testing session was significant, and the immediate competition effect was close to 0 ms.

associated with a novel word (e.g., *cathedruce*), the only matching entry is an existing, phonologically-related, word (e.g., *cathedral*). Exposure to the novel word therefore builds up activation of the existing word, which temporarily strengthens the lexical representation of this existing word. This results in facilitation. In contrasts, when the novel word's lexical entry has been established, it competes with *cathedral* through lateral inhibition, much like existing words inhibit access to similar existing words. Gaskell and Dumay (2003) replicated this effect with a bigger delay training and testing (1 week) and a more implicit test that did not require participants to make an explicit judgment (a pause-detection task, which consists in detecting a 200-ms pause in spoken words, e.g., *cathedr_uke*).

The design of the studies by Gaskell and Dumay (2003) was adapted to novel word learning in the written modality by Bowers, Davis, and Hanley (2005). Native English speakers were trained on novel words based on English words (e.g., *banara*) through a typing task. Immediately after training, participants performed a semantic categorization task.⁹ A second semantic categorization task was performed the second day of the experiment, then more training was administered, then a third semantic categorization task was performed. Results indicated that training on novel words did not lead to significant lexical competition immediately, but lexical competition was visible after a sleep interval, and still present after further training. These results are suggestive of the emergence of lexicalized representations for novel written words, but it is unclear whether the absence of lexicalization immediately after training is a consequence of low power, as some inhibition was present (no interaction was reported).

Tamminen and Gaskell (2008) examined whether novel word learning and lexicalization evidenced in earlier research have a long-lasting impact on the lexicon, and the impact of order or acquisition. They conducted an 8-months longitudinal study on native English speakers using auditory novel words similar to the ones introduced by Gaskell and Dumay (2003). Training on novel words took place over multiple sessions, some of them separated by intervals of multiple months. Some novel words were introduced early in the process, and others were introduced later. Importantly, no retraining of already-trained novel words occurred, such that the cumulative frequencies of all novel words were similar.

The authors hypothesized that novel word lexicalization would be long-lasting and that novel words introduced earlier would be advantaged in the naming task, mirroring age-of-acquisition effects reported in the psycholinguistic literature (e.g., Johnston & Barry, 2006). Results revealed that novel

words have a long-lasting effect on the lexicon, as competition in the lexical decision tasks was still present after 8 months for the words learned early in the process.¹⁰ A period of 4 months with no retest did not eliminate competition effects. Order of acquisition effects similar to the ones evidenced were also found, with words learned earlier being named faster in a naming task (although these effects were not systematically present). This led the authors to conclude that the lexical representations for novel words are unlikely to be episodic traces of auditory sequences, but rather resemble representations of existing words, in that they interact with phonological neighbours and that they are associated with order of acquisition effects.

Dumay and Gaskell (2012) investigated the role of similarity with existing words in novel word learning and lexicalization. They specifically tested whether lexical competition effects found in earlier work (e.g., Gaskell & Dumay, 2003) arise from the activation of the novel words' episodic traces (e.g., *cathedruce*) when encountering a similar existing word (e.g., *cathedral*; see Qiao, Forster, & Witzel, 2009, reviewed below).

The authors reasoned that reduced similarity between novel and base word should reduce the likeliness to activate the novel word when encountering the base word (and vice versa). Native English speakers on fully embedding competitors (e.g., *lirmucktoze* includes the existing word *muck*), as well as cohort competitors (e.g., *cathedruce*). The authors hypothesized that if lexical competition arises from similarity between novel and existing words, competition should be stronger for cohort competitors like *cathedruce* compared with words like *lirmucktoze*. Participants were trained with a phoneme-monitoring task, then tested immediately, after 24 hours and after a week through a free recall task, a forced-choice task, a pause-detection task (Experiment 1), and a word-spotting task (Experiment 2).

The results of Experiment 1 indicated that no competition was present immediately, but that it emerged after 24 hours and was still present 1 week after training.¹¹ The pattern was the same for fully embedding competitors and final deviation words. In contrast, the results of the word-spotting task in Experiment 2 showed that fully embedding competitors were associated with immediate facilitation, then inhibition 24 hours and 1 week later, whereas no effect was associated with final-deviation words.¹² The authors concluded that it is unlikely that these effects come from the strengthening of episodic traces for novel words, as competition was stronger for

⁹ A semantic categorization task requires participants to make a decision regarding the semantic category of the words presented. In this specific study, participants had to categorize the base words (e.g., *banana*) as members of the natural or artefact categories.

¹⁰ The interaction of competitor acquisition and testing session was significant, and the difference between words with a novel neighbor and control words was significant at all test sessions, except for the first one (the difference was the smallest during the first test).

¹¹ The crucial interaction of competitor acquisition and testing session was significant, and the immediate competition effect was close to 0 ms.

competitors that were very different phonologically from their base word.

Tamminen and Gaskell (2013) conducted two experiments to investigate learning and sleep-related lexicalization of meaningful novel written words in native English speakers. In Experiment 1, participants were familiarized with a first set of novel words (“remote” novel words, e.g., *feckton*) through a word-to-meaning matching task, a meaning-to-word matching task, a meaning recall task, and a sentence plausibility task. In a second session, conducted 1 day or 1 week after the first one, participants were trained on a second set of novel words (“recent” novel words) with the same tasks. Finally, they were tested on meaning recall and a primed lexical decision task with novel words used as semantic primes (e.g., *feckton*, which was associated with the meaning “a type of cat with blueish grey stripes,” was used as a prime for the word *kitten*).

Results indicated that meaning recall was superior for recent compared with remote words, and for participants in the 24-hour delay condition compared with participants in the 1-week delay condition. However, in both groups, only “remote” novel words primed existing English words.¹³ These results suggest that, if explicit memory of novel word tends to decrease after a period of sleep, this period of sleep is crucial to the lexicalization of these words. Experiment 2 replicated these effects and indicated that administering the meaning recall task before the primed lexical decision task did not impact semantic priming. This suggests the priming effects do not depend on recent explicit exposure to the primes. Overall, these results suggest that even if participants were not reading the novel word primes consciously (as these were masked), novel words still primed semantically related words. It is therefore more likely that these effects reflect automatic activation of consolidated novel words rather than strategic processing. This suggests that novel words’ meanings had been lexicalized after a sleep interval.

Bakker, Takashima, van Hell, Janzen, and McQueen (2014) investigated the interaction between training and testing modalities in a series of four experiments on monolingual Dutch speakers. Across all experiments, participants were tested immediately after training, 24 hours later, and 1 week later. Two experiments tested competition between novel and existing words in the same modality (auditory in Experiment 1, visual in Experiment 3).

In Experiment 1, competition (in a pause-detection task) was absent initially, but appeared 24 hours later and was still

present 1 week later. The emergence of competition on the second day correlated with decreased episodic recognition performance (assessed through an auditory forced-choice task). Experiment 3 revealed a similar pattern for visual words using a visual semantic decision task. No changes in episodic recognition performance were found. The other two experiments tested competition between novel and existing words in different modalities (Experiment 3: visual novel words, auditory existing words; Experiment 4: auditory novel words, visual existing words). Experiment 3 revealed the presence of competition in the pause-detection task, but this effect was only visible after 1 week. In Experiment 4, competition emerged earlier (24 hours after the first day), and this emergence correlated with reduced episodic recognition performance. Competition was still visible after 1 week.¹⁴

Taken together, these results indicate even though lexical competition was faster to emerge when training and testing modalities were the same, it still emerged across modalities. Moreover, decreased episodic recognition performance correlated with the emergence of competition, suggesting weaker episodic traces for novel words. The whole pattern is suggestive of the gradual emergence of abstract lexicalized representations for novel words that are not modality specific.

In a series of three experiments, Kapnoula and Samuel (2019) explored the role of changes in speaker identity on novel word learning and lexicalization. Participants were Spanish–Basque bilinguals (L1 Spanish), and they were presented with auditory novel words paired with three pictures of the same kind of object over the course of multiple trials (e.g., three different kites).¹⁵ Three different speakers recorded the novel words. Certain pictures were systematically associated with a specific speaker (indexical trials), others were not (uncorrelated trials). Participants were tested immediately after training with a similar task, during which they were asked to select the object corresponding to an auditory novel word among four items (their eye movements were also recorded). Crucially, there was no strict speaker-to-picture correspondence for any word during test. Experiment 3, which included a sleep manipulation between training and test (24 hours interval), revealed that the speed at which the correct referent of a novel word was fixated was higher for indexical trials, although the effect of speaker identity was numerically smaller—although not significantly—than the one observed in Experiment 1 and 2. This suggests that sleep supports the

¹³ The crucial interaction of type of competitor, competitor acquisition, and testing session was significant, with a significant flip from facilitation to competition between Day 1 and 2 for the fully embedding competitors.

¹⁴ It should be noted that although priming was significant only for the remote primes, the interaction between priming and time of training was not significant. This suggests that the experiment was potentially underpowered for the detection of the interaction. The same pattern was evidenced in Experiment 2.

¹⁴ The interaction of testing session and condition was significant overall and between Days 1 and 2 in Experiments 1, 2, and 4. Competition effect was close to 0 ms for these experiments, whereas, for Experiment 3 competition was close to 0 ms on both Days 1 and 2.

¹⁵ Participants were instructed that they would learn new words and their meanings. The instructions did not specify whether these novel words were new Spanish words, new Basque words, artificial words, or words from another language. However, all novel words were morphologically consistent with Spanish but not with Basque (an agglutinative language).

formation of abstract representations for novel words, which is consistent with the CLS account.

Importantly, as participants were unaware of correspondences between voices and pictures, it is unlikely that the effects come from the strengthening of episodic memories, which are normally accessible to conscious awareness. Instead, this suggests that lexical representations may be impacted by indexical information, but that this influence may weaken over time, as the number of speakers and the number of contexts associated with a novel word increase. This has interesting consequences for bilingual novel language learning.¹⁶ Because bilinguals usually have reduced experience with each of their languages compared with monolinguals of their L1/L2, indexical information may decrease more slowly. Indexical information may also be more consistent for bilingual individuals compared with monolingual individuals, especially if one considers compartmentalized bilinguals, who use each of their languages in different, separated social contexts. Finally, indexical information may be a more valuable cue for bilingual individuals compared with monolingual individuals, as it may help bilinguals to identify the target language the novel word belongs to.

Wang et al. (2017) conducted a study similar in its design to the study by Bowers et al. (2005). Participants were also assigned either to the AM group, first retested 12 hours after training with no sleep interval, or to a PM group, first retested 12 hours after training with a sleep interval. Both groups were retested 24 hours after training. Results were consistent with prior studies, with competition emerging in the first retest only in the PM group, but not in the AM group.¹⁷ Recall was also worse in the morning group after 12 hours compared with the afternoon group. Lexical competition and recall performance were similar across groups after 24 hours. This suggests that sleep promotes the emergence of lexicalized representations, and also has a protective effect on episodic memories.

Studies inconsistent with the predictions. Qiao, Forster, and Witzel (2009) conducted a replication of Bowers et al. (2005). The authors' goal was to assess whether the effects found in Bowers were due to lexicalization of the novel words, as claimed by Bowers et al. (2005), or the effects were dependent upon a strong episodic trace for the novel words. To determine that, the authors used a lexical decision task with a masked priming paradigm. As mentioned before, masked priming effect depends on the status of the prime, as nonword primes (e.g., *contrapt*) facilitate processing of the target (e.g., *contract*), contrary to word primes (e.g., *contrast*; e.g., C. J. Davis & Lupker, 2006)—an effect known as the *prime lexicality effect*. The authors predicted

that if novel words became lexicalized at some point in the experiment, they should not facilitate processing of orthographically related targets. Native English speakers underwent the same training procedure on the novel words used in Bowers et al. (2005). Results showed that masked novel words primed (facilitated) target words on the first lexical decision task and that this facilitation was maintained after sleep. In contrast, word primes did not facilitate target words on either day. Sleep therefore did not reduce the prime lexicality effect for novel words, suggesting that no sleep-related lexicalization of the novel words had occurred during the sleep interval.

The authors concluded that novel words may still depend on the episodic memory system, even after a sleep interval, and that the effects evidenced in Bowers et al.' (2005) study actually reflect a postaccess spelling check triggered by the episodic memory traces of the novel words. The discrepancy between this study and Tamminen and Gaskell (2013) suggests that training intensity may play a role in the emergence of lexicalization.

Sobczak and Gaskell (2019) explored the effects of an incidental training regimen on form-only novel word learning in a series of four experiments. Specifically, they compared the effect of an incidental Hebb repetition task (see Szmalec, Page, & Duyck, 2012, reviewed below) with the more intentional phoneme-monitoring task used in earlier literature. Participants were asked to recall sequences of syllables presented aurally, with one particular sequence repeated frequently. These particular sequences contained novel words that were orthographic neighbors to English base words. In Experiment 1, participants were trained in the morning on Day 1 through either a phoneme monitoring task or a Hebb repetition task. Participants were tested immediately after training and retested 12 and 24 hours later (pause-detection task, cued recall,¹⁸ forced-choice task). Results indicated that no lexicalization of novel words had taken place in either training conditions after 24 hours, while the phoneme monitoring group performed better in the forced-choice task compared with the Hebb repetition group.¹⁹

The authors concluded that exposure was not sufficient to lead to lexicalization, regardless of learning regimen. Experiment 2 replicated these findings, despite the inclusion of pauses to help participants delimit the novel words within the sequences. This suggests that inferior memory performance in the Hebb repetition group was not caused by the absence of chunking cues. Increasing the amount of exposure led to lexical

¹⁶ It is worth mentioning again that participants in Kapnoula and Samuel (2019) were Spanish–Basque bilinguals.

¹⁷ The interaction of group, condition, and testing session was significant overall. The interaction of group and condition was significant only for the second testing session, not for any other session. The competition effect was close to 0 ms in both groups for the first testing session.

¹⁸ A cued recall task is a recall task in which participants are cued with the onset of a word and have to retrieve it.

¹⁹ The interaction of type of training, testing session and competitor was not significant, nor were any of the two-way interactions.

competition effects, as well as enhanced episodic recall and recognition, in the phoneme-monitoring group, but not in the Hebb repetition group (Experiment 3). Finally, using novel words that were more similar to existing English words did not lead to lexicalization in the Hebb repetition task (Experiment 4).²⁰ Overall, these results suggest that intentional learning conditions (e.g., phoneme-monitoring), but not incidental learning conditions (e.g., Hebb repetition task), lead to the lexicalization of novel words.

Interim summary. Overall, episodic knowledge for novel words, indexed by accurate episodic recognition and/or recall immediately after exposure and after a delay, is evidenced across multiple studies (e.g., Bakker et al., 2014; Dumay & Gaskell, 2012). Moreover, several studies highlight a delayed emergence for lexicalized representations (e.g., Gaskell & Dumay, 2003; Wang et al., 2017). These representations exhibit several characteristics that are proper to existing words and that distinguish them from episodic representations. For example, their interaction with existing representations is automatic and not mediated by awareness (e.g., Dumay & Gaskell, 2012; Tamminen & Gaskell, 2013). However, training intensity (Qiao et al., 2009) and type of training (explicit vs. implicit, Sobczak & Gaskell 2019) may impact the emergence of lexicalized representations. Finally, there is also some evidence that there is an inverse relationship between explicit knowledge of a word form/meaning and the strength of lexical competition (Bakker et al., 2014; Tamminen & Gaskell, 2013), although this relationship was not systematically observed (e.g., Wang et al., 2017).

Is sleep crucial to novel word lexicalization, and if so, how?

One of the CLS account's predictions is that off-line consolidation plays a crucial role in the emergence of neocortical representations for novel words, in that it allows novel words to become interleaved with existing lexical representations in the mental lexicon of an individual. Sleep is an ideal state for this interleaving to occur, because the cognitive system is not actively processing novel information (McClelland et al., 1995). Specifically, hippocampal representations are posited to be reactivated during slow-wave sleep and to prime related neocortical representations, thus promoting the interleaving of new knowledge with older representations. However, the development of neocortical networks may also occur during wake through interleaved exposure to existing and novel words (e.g., McClelland et al., 1995).

²⁰ In Experiment 2, the interaction of testing session and competitor was not significant. In Experiment 3, the interaction of type of training and competitor was significant for the phoneme-monitoring group only. The three-way interaction of type of training, competitor, and session was not significant. In Experiment 4, the interaction of testing session and competitor was not significant, and competition effects were close to 0 ms.

Studies consistent with the predictions. It was unclear whether Gaskell and Dumay's (2003) findings, reviewed above, were due to sleep itself or simply to time passing. Dumay and Gaskell (2007) attempted to address this question. Using methods similar to the ones in Gaskell and Dumay (2003), the authors trained native English speakers on novel words that were embedding competitors—competitors that are not derived from the base word, but include it (e.g., *shadowks*). Participants were also assigned either to the AM group, first retested 12 hours after training with no sleep interval, or to a PM group, first retested 12 hours after training with a sleep interval. Both groups were retested 24 hours after training. Results indicate that there were no group differences in the forced-choice task, which was generally high for all three test sessions.²¹ Pause-detection latencies did not differ across the two groups immediately after training.

In contrast, lexical competition emerged 12 hours after training for the afternoon, but not the morning group.²² Performance in free recall also increased for the afternoon group, but not the morning group. Both groups, however, exhibited lexical competition in the final pause-detection task and enhanced recall 24 hours after training. Interestingly, participants who recalled more novel words were also the ones exhibiting increased competition between base and novel words. Taken together, these results suggest that novel words lexicalization is dependent on sleep, not solely on time passing. However, the level and type of intervening activity between the first and second session in the morning group was uncontrolled, such that many factors may explain the absence of lexicalization in this group. Moreover, this study highlighted the relationship between explicit memory (recall) and sleep-related lexicalization, although it is unclear whether better explicit memory predicts stronger sleep-related lexicalization or the opposite.

Tham, Lindsay, and Gaskell (2015) sought to extend the conclusions of prior research on novel words lexicalization to nonalphabetic scripts. Monolingual English speakers were trained on Mandarin characters (e.g., 火) paired with animal names (e.g., *cow*).²³ The design was similar to prior studies, with participants assigned either to an AM group (no sleep interval between training and test) or to a PM group (sleep

²¹ To avoid circadian confounds in amount of initial acquisition, the authors analyzed performance of two subgroups of participants matched on initial performance in free episodic recall and recognition (the full sample was therefore not analyzed).

²² The interaction of group, testing session and competitor was significant for Session 2 and 3 combined. There were no significant differences between groups before sleep (competition effects close to 0ms), and no differences 24 hours after initial training.

interval between training and test). The authors were specifically interested in the emergence of size congruity and semantic distance effects for novel words, which are indexes of automatic semantic access characteristic of existing words. When asked to select the largest of two words (in terms of font), participants are usually faster to respond when these are congruent with the size of their referents (e.g., *bee* written in a smaller font than the word *cow*; see Paivio, 1975). Participants also tend to respond faster when the referents have large size differences (e.g., *bee–cow*) compared with smaller size differences (e.g., *fox–cow*).

Size congruity effects for novel characters were observed in the afternoon group, but not in the morning group. In contrast, size congruity effects for existing English control words were similar across groups, suggesting that the difference observed for novel characters was not due to circadian rhythm effects. Semantic distance effects were also observed in both groups.²⁴ This pattern of results suggest that lexicalization may happen during wake, but that it is shallower than during sleep, as only semantic distance effects were observed in the morning group. The authors hypothesized that novel language learning may be initially mediated by the native language, and sleep may make the link between the novel L2 words and meaning more direct. This study was the first, to our knowledge, to show evidence of novel word lexicalization across different scripts.

Studies inconsistent with the predictions. Szmalec et al. (2012) explored implicit word learning procedures by using a Hebb repetition paradigm. Across two experiments, Dutch speakers²⁵ recalled sequences of visually presented syllables, with one particular sequence repeated every third trial. These particular sequences contained novel words that were orthographic neighbors to Dutch base words. Twenty-four hours later, participants were tested through an auditory lexical decision task (Experiment 1) and/or an auditory pause-detection task (Experiments 1 and 2). Results of Experiment 1 indicated that novel words were consolidated in lexical memory after 24 hours. In Experiment 2, participants were tested immediately after training, retested after a 12-hour delay (which included a sleep interval or not) and again after a 24-hour delay. Competition with base words was not evidenced initially, but only after 12 hours and after 24 hours.

Crucially, there were no differences between participants tested 12 hours after training on the same day and

participants tested 12 hours after training and a sleep interval.²⁶ The results are therefore consistent with the idea that novel words are integrated in the mental lexicon in a two-stages fashion, but they call the role of sleep in this integration process into question. The reason behind the discrepancy between this study and Sobczak and Gaskell (2019) is unclear—it is possible that the nature of the filler items (nonoverlapping test and filler items in Szmalec et al., 2012; overlapping in Sobczak & Gaskell, 2019) may have crucially impacted how sequences were learned.

The respective roles of sleep and exposure were investigated by Lindsay and Gaskell (2013) in a series of three experiments on native English speakers. The design of these experiments is close to the one of earlier studies by Gaskell, with some important differences. In Experiment 1, training (phoneme-monitoring) and test (lexical decision task, familiarity judgment) were fully interleaved, such that participants were trained and tested on novel words during each of the four experimental session on the first day. Competition emerged during the third session, was stronger in the fourth session, and was still present after sleep. Training modalities in Experiment 2 were similar, but participants were not tested with a lexical decision task before the fourth (last) session of the first day. This lexical decision task did not reveal the presence of competition, whereas competition was found 24 hours later. Experiment 3 tested whether replacing spaced training by a massed initial training session would impact lexicalization. Results were similar to Experiment 1, although competition appeared later on the first day and was weakened after sleep. Recognition was higher after sleep in all experiments.²⁷

Taken together, these results suggest that sleep is a sufficient, but not a necessary condition for novel word lexicalization. What is crucial is the exposure to existing representations (through a lexical decision task, for example), which could induce plasticity and promote novel word incorporation into the mental lexicon. This is consistent with the CLS account, as it predicts that interleaving may occur during wake as a consequence of interleaved exposure to existing words and novel words (McClelland et al., 1995). These effects may be mediated by awareness (driven by the similarity of novel and

⁰ The characters selected were not the actual Mandarin characters for animal names (these were judged too complex for the learning task).

²⁴ The interaction of size congruity, group, and language was marginally significant. The interaction of group and language was significant for Mandarin characters only, not for English control words. Size congruity was significant only for participants in the sleep, not the wake group (effect close to 0 ms). The interaction of semantic distance, group, and language was not significant. The effect of semantic distance was significant for both languages and across both groups.

²⁵ It is unclear whether the participants were native speakers.

²⁶ The interaction between time of testing and group was not significant. Competition was close to 0 ms in both wake and sleep groups immediately after training, and significant competition was evidenced in both groups 12 hours and 24 hours after initial training.

²⁷ Across all experiments, the interaction between testing session and competitor acquisition was significant, there was no significant competition evidenced during the first testing session (effect close to 0 ms), whereas competition was consistently significant at later time points. Competition was significantly increased on Day 2 in Experiments 1 and 2, but not 3 (Cohen's *d*).

existing words), although the results of Dumay and Gaskell (2012) reviewed above suggest that it is not the case.

McGregor (2014) investigated the role of retrieval on episodic recognition and recall of novel words in English speakers.²⁸ These words were paired with referents during a training phase. All participants were tested immediately after training, then retested either 2 hours after training, 12 hours after training, or not retested on the same day.²⁹ All participants were retested 24 hours after training. Importantly, no test of lexical competition with existing words is reported in the article, such that we only discuss results on the episodic recognition and recall tasks.

There was no effect of interim test on episodic recognition accuracy. Recognition speed, however, was faster during the final retest for both participants in the 12 hours interim retest condition and for participants in the no interim retest condition, suggesting stabilization of the memory trace, but not for participants in the 2 hours retest condition. In contrast, recall accuracy was superior for participants in both interim retest conditions compared with participants in the no retest condition. This pattern of results suggests that forcing retrieval can disrupt lexicalization of a still-labile memory trace (see Alberini, 2005). However, forcing retrieval may have benefits, as it can yield additional learning. This is overall consistent with the idea that novel word traces are not consolidated immediately, but suggests that sleep may not be a crucial factor for novel word episodic recognition and recall.

Geukes, Gaskell, and Zwitserlood (2015) tested under which conditions statistical learning would lead to novel word competition with existing words in a series of three experiments on native German speakers. Across all experiments, participants were presented with novel written words paired with German color words in a regular, but not systematic way (e.g., novel word *alep* was paired with color word *blau* [blue] more often than with color word *grün* [green]). They were then tested on a classic Stroop task immediately after training and 24 hours later. In Experiment 1, the Stroop task included both novel words and German color words. Stroop congruency effects were found (i.e., reaction times for *alep* written in blue were faster than reaction times for *alep* written in green), that were bigger for German than for novel words. These effects emerged immediately after training and increased after sleep, specifically for novel words.

In Experiment 2, training was less intensive, but the effects were still present (although they were reduced). The inclusion of neutral trials in Experiment 2 revealed that the effect of novel words was more inhibitory than facilitatory, as revealed

by the significant contrast between control trials and incongruent trials. Finally, Experiment 3 revealed that removing German color words from the Stroop task delayed the emergence of Stroop effects, which only appeared after sleep.

This suggests that interleaving existing and novel words provides contextual information that may promote the immediate emergence of competition. It is unclear, however, whether the presence of existing color words increased the activation of the semantic field of color, or if they provided a mediating link between novel word and color semantics. After an off-line period, contextual information is no longer needed, which is consistent with the CLS predictions (although the emergence of competition immediately after learning is not). The hypothesis of L1 as a mediating link echoes a famous model from the bilingual literature that predicts that the link between L2 words and concepts are initially mediated by L1 (revised hierarchical model; Kroll & Stewart, 1994).

Kapnoula, Packard, Gupta, and McMurray (2015) took a different approach to investigate novel word learning and lexicalization. The authors trained native English speakers on novel words based on English words through two verbal tasks (a listen-and-repeat-task and a stem-completion task). Participants were then tested with a visual world paradigm. In this task, participants were presented with four target objects: a target object (e.g., a cup), a filler object with the same onset as the target one (e.g., a car), and two unrelated fillers (e.g., a duck, a book). Participants had to select the object presented aurally. The aural stimuli were recorded using splicing: the target word (e.g., *cup*) was recorded, as well as existing competitors like *cub* and novel word competitors like *cud*. The onset *cu-* was taken from one of the competitors and merged with the final consonant of the target word (e.g., *-p*). Studies that have used splicing have found that, because of coarticulation, the vowel is slightly different in spliced words, which generates lexical inhibition and leads participants to fixate the target object less. Importantly, this effect is usually only found when the splicing combines two existing words (e.g., *cub* + *cup*), not a novel word and an existing word (e.g., *cud* + *cup*). Kapnoula et al. (2015) hypothesized that training participants on novel words like *cud* may lead to inhibitory effects analogous to the ones found for existing words.

Experiment 1 confirmed this hypothesis—novel words directly competed with existing words after minimal training, with no interleaving and with no off-line period. In contrast, spliced stimuli combining untrained novel words with target words were not associated with competition. Experiment 2 replicated this finding with a different, less effortful training (phoneme-monitoring task), suggesting that these results were not crucially dependent on training characteristics. Importantly, there was no retest after a sleep interval, so it is unclear whether these effects may or may not be strengthened after sleep. Nevertheless, this study is at odds with CLS predictions.

²⁸ It is unclear whether these participants were native English speakers.

²⁹ Half the participants in the 2-hours delay condition napped, and half the participants in the 12-hours delay slept. There were no differences within each group in either episodic recognition or recall, so the subgroups were collapsed. To avoid circadian confounds, immediate performance after training across the three groups was compared, and no difference was found.

The authors argue that the discrepancy with prior novel word lexicalization studies may be explained by task differences: lexical decision tasks may not measure lexical competition specifically or be too coarse to detect subtle, immediate competition. It is therefore possible that sleep is necessary for lexical knowledge to become embedded in the complex system enabling listeners to make lexical decisions. Nevertheless, this study suggests that lexicalized representations for novel words can emerge before sleep.

Himmer, Müller, Gais, and Schönauer (2017) investigated the relationship between different learning regimen for written novel words, sleep, and circadian rhythm in native German speakers. Participants were assigned to an explicit encoding condition or to a fast-mapping condition, and were split into an AM and a PM group.³⁰ Items were not artificial novel words, but very low-frequency German words. In general, performance on a three-alternative forced-choice (3AFC) task declined after sleep, and performance was lower in the fast-mapping group compared with the explicit encoding group. However, significantly less forgetting was observed in the fast-mapping group than in the explicit encoding group in the absence of a sleep interval.

The presence of a sleep interval was also associated with reduced forgetting in the explicit encoding group, not in the fast-mapping group. This suggests that when novel words are learned implicitly, the importance of sleep for lexicalization is reduced. Importantly, memory performance immediately after training was not correlated with forgetting after sleep or wakefulness, indicating that time of day effects did not entirely explain the effects of sleep. Finally, fast mapping was associated with better performance in the PM group, whereas explicit encoding was associated with better performance in the AM group. This highlights the importance of circadian rhythm effects on novel word learning—word learning regimen may differ in terms of recruitment of executive functions, which have been shown to be modulated by circadian rhythm (e.g., Schmidt, Collette, Cajochen, & Peigneux, 2007).

Walker, Henderson, Fletcher, Knowland, Cairney, and Gaskell (2019) examined the impact of delay between learning episode and sleep, and the impact of training intensity on novel word learning and lexicalization. The materials, training and test procedures were similar to Bowers et al. (2005) and to Wang et al. (2017), but the study spanned over 4 days, distributed over 2 weeks. Participants were trained and immediately tested four times on a first set of novel words during Day 1. They were then retested on Day 2 shortly after waking up.

During Week 2, participants learned a second set of novel words following the same procedures, and a final retest of Week 1 novel words was included. Importantly, training intensity varied between Weeks 1 and 2 (exposure to novel words during Week 2 was increased or reduced compared with Week 1).

Experiment 1 indicated that lexical competition emerged in a semantic categorization task immediately after training, and that it was stronger after sleep. Recall was also improved after sleep. Training intensity did not impact this pattern. Finally, delay between novel word learning and sleep did not impact performance at retest on Day 2, but more time between novel word learning and sleep was associated with better episodic recall and recognition on Day 4 (1 week later). Experiment 2 replicated these findings with lower exposure to novel words (five presentations), although lexical competition before and after sleep were similar.³¹

Overall, these results suggest that lower exposure leads to memory traces for novel words that may be too weak to benefit from sleep. Weaker encoding may still be sufficient for lexicalization to appear in explicit tasks (recall). The intriguing result that increased time between learning and sleep leads to better performance 1 week later suggests that retesting on Day 2 may bring additional learning, which is consistent with the insights of McGregor (2014). Finally, the finding that competition arises immediately after training is at odds with a putative crucial role for sleep, and may be a consequence of generally slower reaction times in this study compared with earlier ones (of note, this study was web-based).

Interim summary. Although many of the studies reviewed earlier suggested an emergence of lexicalization after a sleep interval, a substantial number of studies reviewed in this section highlight a richer variety of time courses for lexicalization. Several studies, for instance, have found evidence of immediate lexicalization effects (e.g., Geukes et al., 2015; Szmalec et al., 2012; Walker et al., 2019). As hypothesized by Lindsay and Gaskell (2013), sleep may be a “sufficient, but not necessary condition” for lexicalization, as interleaving of new and old knowledge during training may actually suffice to promote the emergence of lexicalization. Importantly, lexical decision tasks may be too coarse to detect subtle competition (see Kapnoula et al., 2015).

³⁰ Explicit encoding refers to a training condition in which the mapping between a novel word and its referent is explicitly presented to the participant, whereas fast mapping involves the presentation of two potential referents for a given novel word, with no explicit information about the correct mapping. We return to this distinction in more details in the review of Coutanche and Thomson-Schill (2014) below.

³¹ In Experiment 1, the interaction between testing day and competitor was significant. The change in lexical competition across days of testing was significant, although competition was present before sleep. The interaction between testing day, delay and competitor was also significant. In Experiment 2, there were no significant interactions, only a main effect of competitor.

What is the role of prior knowledge in the establishment of novel word representations? A schema is a network of interconnected neocortical representations that impacts information processing (van Kesteren et al., 2012). Within the CLS account, consistency with existing representations (i.e., schemas) may facilitate the integration of new knowledge in memory networks, by activating phonological/orthographical or semantic representations in the language (e.g., English). Inconsistency—as in the case of novel words that do not resemble existing words—may slow down this process (see McClelland, 2013). This distinction is thought to prevent catastrophic interference.

Dumay, Gaskell, and Feng (2004) constructed two experiments to compare the time course of lexicalization for form-only versus meaningful novel words. In Experiment 1, native English speakers were trained on spoken words through either a phoneme-monitoring task or a semantic verification task (which consisted in the presentation of novel words in definitions and semantic contexts, such as “A cathedruke is a variety of vegetables. The cook served the boiled cathedruke with a steak and baked potatoes.”). Participants were tested immediately after training, 24 hours later and 1 week later with a primed lexical decision task, a forced-choice task, and a free association task. Results indicated that episodic recognition, indexed by the forced-choice task, was overall better 1 week after training than on the first and second day, which did not differ from each other. However, episodic recognition was better for form-only novel words compared with novel words with meaning on the first day. Competition emerged on Day 2 when novel words were form only, whereas it emerged only 1 week after for meaningful novel words. Taken together, these results suggest that the integration of meaningful novel words may require more time than sleep-related lexicalization of novel word forms with no meanings. Experiment 2 replicated the finding that form-only novel words are consolidated rapidly using a pause-detection task.³²

Leach and Samuel (2007) investigated sleep-related lexicalization for completely novel words—novel words that are not based on existing English words (e.g., *penivasher*).³³ The authors introduced two crucial concepts in the word-learning literature: lexical configuration and lexical engagement. Lexical configuration corresponds to the factual knowledge about a word (i.e., its phonemes, orthography, meaning, and syntactic properties), characteristic of episodic representations. Lexical engagement refers to the capacity of a word to interact with other words during lexical access, which is characteristic of lexicalized representations. In Experiment 1, native English speakers were trained on form-only novel words

that were not based on English words through a phoneme-monitoring task. Participants were trained and tested on 5 consecutive days. Tests included a forced-choice task and a words-in-noise task (thought to probe lexical configuration), a phonemic restoration task and a perceptual learning task (thought to probe lexical engagement).³⁴

Results indicated that lexical configuration, as indexed by performance on the forced-choice task and on the words-in-noise task, was not established immediately after training, but increased steadily over time. However, performance in the phonemic restoration task did not reveal the presence of significant lexical engagement, suggesting that lexical engagement effects take longer to emerge for novel words that are not based on existing words.³⁵ In Experiment 2, participants were trained on novel words paired with pictures through a picture–word association task similar to the ones used in cross-situational statistical learning research (e.g., Yu & Smith, 2007). Each novel word was presented with two pictures of unfamiliar objects and participants were asked to pair each novel word with the correct picture. Results indicated similar an increase in lexical configuration similar to Experiment 1. However, lexical engagement was enhanced compared with Experiment 1 and increased steadily over time.³⁶

In Experiment 3, novel words were introduced to participants through a series of spoken stories. Each story mentioned a novel word six times in different contexts (e.g., “The bibershack had four valves, like the human heart. The survival

³³ These novel words were pronounceable and phonotactically legal in English. Because these words were completely novel, they did not have any phonological/orthographical or semantic neighbors. However, the authors did not mention other characteristics, such as bigram frequency (as is the case of many studies reviewed here). Because high bigram frequency is associated with enhanced novel word learning (e.g., Bartolotti & Marian, 2017; see Chetail, 2015, for a review), we calculated average bigram frequency for the stimuli using CLEARPOND (Marian, Bartolotti, Chabal, & Shook, 2012). The average bigram frequency was low (grand mean = .007), and no bigram frequency was higher than .018, suggesting that novel words were “unwordlike” (see Bartolotti & Marian, 2017, for a comparison. This might have impacted the results.

³⁴ A words-in-noise task consists in the presentation of auditory novel words masked with noise and progressively unmasked. Participants have to recognize the words as fast as possible. A phonemic restoration task consists in the presentation of a novel word containing either an added noise segment or a noise segment replacing one phoneme. Noise segments usually go unnoticed if lexicalized representations are established. A perceptual learning task consists in the presentation of auditory novel words, in which one fricative segment, either /s/ or /ʃ/, is systematically replaced with an ambiguous segment between /s/ and /ʃ/. Then, participants are asked to categorize ambiguous fricatives presented in untrained novel words on a continuum between /s/ and /ʃ/ (e.g., /asa/–/aʃa/). Because established lexical entries can modify the perception of phonetic categories (e.g., Norris, McQueen, & Cutler, 2003), it is hypothesized that participants trained on novel words in which /s/ was systematically ambiguous would categorize ambiguous fricative segments in untrained novel words as /s/. Conversely, participants trained on novel words in which /ʃ/ is systematically ambiguous are predicted to categorize ambiguous fricative segments in untrained novel words as /ʃ/.

³⁵ There was no interaction between exposure (/ʃ/ vs. /s/) and day of testing and no significant perceptual learning effects on any day.

³² In Experiment 1, the interaction of day and competitor was significant. Competition was significant for phonological exposure only 24 hours after training, not for semantic exposure. In Experiment 2, the interaction of day and exposure was marginally significant (facilitation), and the effect switched to inhibition 24 h later and 1 week after.

rate with the bibershack was very encouraging.”). Then, participants answered comprehension questions about the novel words’ meaning. Participants were tested through a perceptual learning task. Performance on that task was better compared with Experiment 1, but not as good as Experiment 2.³⁷ Results of Experiments 4 and 5 indicated that adding a production component to the phoneme-monitoring task, or to the picture–word association task, was associated with enhanced performance in the word-in-noise task but decreased performance in the perceptual learning task compared with Experiments 1 and 2.³⁸

Taken together, these results highlight the distinction between learning “facts” about novel words (e.g., how they sound) and developing robust lexical representations. Importantly, the development of lexical representations was not immediate, but appeared after a sleep interval and generally increased over time. Picture association, but not phoneme-monitoring, reliably led to the development of lexical engagement. This suggests that, compared with the development of lexicalized representations for novel words that resemble closely existing words (e.g., *cathedrue*), developing representations for completely novel words (which do not benefit from preexisting schemas) might be slower.

Decreased lexical engagement was observed when novel words were introduced through spoken stories compared with picture association, although lexical engagement was still higher than with phoneme monitoring. However, these differences in training limit the comparisons that can be drawn from these experiments. For example, extracting novel word meanings from spoken stories may arguably require more working memory capacity and inference making than phoneme monitoring. Spoken stories may also crucially differ from picture association, as they never mapped novel words to meanings explicitly (and no feedback was provided to the participant). Finally, these results suggest that production promotes phonological encoding by drawing the learner’s attention to the word’s phonology, allowing learners to better recognize this word (lexical configuration). However, this focus on word form might lead to shallower representations, compared with situations that do not require production, leading to decreased lexical engagement.

In a series of four experiments, Fernandes, Kolinsky, and Ventura (2009) investigated the role of statistical learning in novel word learning and lexicalization in Portuguese

speakers.³⁹ The paradigm used was an artificial language-learning paradigm, inspired by the one developed by Saffran, Aslin, and Newport (1996). Participants were exposed to a stream of spoken syllables. In this type of paradigm, words are usually defined as the sequences that have high transitional probability, whereas other sequences have low transitional probability. In Fernandes et al. (2009), novel words were either the sequences with high transitional probabilities (“TP-words”) or the sequences with low transitional probabilities (“part-words”). The authors manipulated features of the novel words such as relative frequency and wordlikeness (i.e., similarity with Portuguese words). Participants were tested immediately after training and 1 week after on a forced-choice task on novel words, and a lexical decision task on base words.

Their results indicated that novel words learned incidentally through an artificial language-learning paradigm compete with existing words immediately. Competition further increased after a 1-week interval. This effect did not depend on frequency, as it emerged even when part-words were as frequent as TP-words. However, when part-words were more wordlike than TP-words, even when they were as frequent as TP-words, there was no evidence of lexicalization, neither immediate nor after an interval of 1 week. Finally, high transitional probability and similarity with existing Portuguese words led to enhanced episodic recognition. These results highlight the importance of prior knowledge on novel word learning, but it is unclear why competition occurs immediately in the case of artificial language learning.

Coutanche and Thompson-Schill (2014) constructed two experiments to investigate the effect of training regimen on novel meaningful word learning in native English speakers. In Experiment 1, participants were assigned either to a fast-mapping group or to an explicit encoding group. In the fast-mapping group, participants had to infer the reference of a novel word, whereas the mapping between novel word and reference was explicit for participants in the explicit encoding condition. Participants then performed a free recall task, a forced-choice task, a semantic categorization task, and a primed lexical decision task (e.g., *torato*—SPIDER). Participants were tested again on the following day.

Superior episodic recall and recognition were evidenced in the explicit encoding group compared with the fast-mapping group on both Day 1 and Day 2. In contrast, participants in the explicit encoding group showed no evidence of novel word lexicalization on either day. Participants in the fast-mapping group, however, exhibited competition in the lexical decision task on both Day 1 and Day 2. Finally, evidence of semantic priming was only found on Day 2, for participants in the fast-

⁰ The interaction was not significant, and the perceptual learning effect was only significant from Day 2 onward. However, the effect was not absent on Day 1, only smaller.

³⁷ The interaction was not significant, and the perceptual learning effect was only significant on Days 2 and 5. However, the effect was not absent on other days, only smaller.

³⁸ In Experiments 4 and 5, there were no interaction between exposure (/f/ vs. /s/) and day of testing, and no significant perceptual learning effects on any day. When comparing Experiments 2 and 5, there was a significant interaction between experiment, exposure, and day of testing

³⁹ No information regarding the language(s) spoken by the participants is reported. We assumed that participants were at least proficient in Portuguese, as the novel words presented were based on Portuguese words.

mapping group. These results suggest that fast mapping seems to promote the rapid emergence of neocortical representations. In contrast, novel words learned through explicit encoding of novel words were not lexicalized, even after an interval of sleep, but these words were also recognized and recalled better than words learned through fast mapping. This suggests that these words were not abstracted from the learning episode, and that episodic knowledge may be irrelevant, and even disruptive, for novel word processing.

In Experiment 2, Coutanche and Thompson-Schill (2014) further showed that one crucial feature of the fast-mapping training is the simultaneous presentation of two potential referents, one of which needing to be rejected. This suggests that the presence of a referent from the same taxonomic class (e.g., another insect) may activate preestablished schemas for this referent and facilitate novel word integration within semantic memory (see McClelland, 2013). This, in turn, might facilitate the anchoring of novel word–referent mappings into semantic memory, which would lead to the rapid emergence of competition.⁴⁰

Henderson, Devine, Weighall, and Gaskell (2015) investigated how native English speakers (adults and children) learned meaningful novel spoken word competitors (e.g., *daffodot*) through incidental exposure. Participants' expressive vocabulary was measured (Vocabulary subtest of the *Wechsler Abbreviated Scales of Intelligence–Second Edition*; Wechsler, 2011). Participants were exposed to novel words through a recorded fictitious story, followed by a comprehension task. They were then tested on a pause-detection task on base words, a cued recall task on novel words, and a forced-choice task on novel words. The same tests were administered on the following day. Results indicated that neither children nor adults exhibited competition effects immediately after training, but it was present on the day following training in both groups.⁴¹

Adults improved more than children in cued recall on Day 2, whereas children improved more than adults in episodic recognition on Day 2 (due to a ceiling effect in the adult group). Interestingly, there was a significant positive correlation between expressive vocabulary scores and overnight improvements in both cued recall and pause detection in the children group. This correlation was not evidenced in the adult group. Taken together, these results highlighted that incidental exposure to novel words in a story context leads to their lexicalization after a sleep interval. This study also revealed remarkable similarities in the novel word sleep-related

lexicalization processes of adults and children, even though adults generally exhibited overall better explicit memory of the novel words. Finally, this study showed that novel word learning depends, at least in children, on preexisting vocabulary depth, as individual differences in expressive vocabulary correlated both with explicit recall and lexicalization of the novel words.

Havas et al. (2018) investigated the role of preexisting semantic and phonological schemas on novel word learning. The authors trained Spanish native speakers on novel words resembling Spanish words or real Hungarian words (a language unknown to the participants). Novel words were paired with pictures of familiar or unfamiliar objects, or no picture. Participants' memory was assessed through an episodic recognition task, a 4AFC task, and a semantic priming task. As in some earlier studies, a 12-hour delay including sleep or wake was imposed between training and test.

Results indicated that performance in episodic recognition and 4AFC was overall lower for novel words with unfamiliar phonology and novel words paired with unfamiliar objects. Recognition was enhanced for participants who slept between training and test, but these effects were limited to participants trained on novel Hungarian words. Performance was higher in the 4AFC task for familiar pictures, but only when paired with novel Spanish-like words. Finally, no semantic priming was evidenced for novel words. These results suggest that consistency with preexisting schemas (e.g., familiar phonology, familiar objects) is important for lexicalization. Representations that are at least partially inconsistent with preexisting schemas were associated with overall lower performance, and more dependence on overnight lexicalization.

It is unclear, however, why novel Spanish-like words did not benefit from a night of sleep, although overall superior memory performance may be associated with reduced opportunity for overnight changes. It is also unclear whether the absence of semantic priming, which contrasts with prior results (e.g., Tamminen & Gaskell, 2013), should be interpreted as an absence of lexicalization or as a reflect of low power (only a subset of the novel words was used during the semantic priming task).

James, Gaskell, and Henderson (2019) investigated the relationship between sleep-related lexicalization for meaningful novel spoken word and neighbourhood density. We do not review Experiment 1 and 3 here, which are exclusively focused on novel word learning in native English-speaking children. In Experiment 2, novel spoken words were presented along with pictures through a repetition task and a multiple-choice quiz (the experiment was web-based). Participants were tested on a cued recall task and a 4AFC task immediately after training, 24 hours later, and 1 week later. They also took a vocabulary test (*Wechsler Abbreviated Scales of Intelligence–Second Edition*; Wechsler, 2011).

⁴⁰ It should be noted that this interpretation, along with the effects of the fast-mapping technique on memory encoding, are controversial (see Cooper, Greve, & Henson, 2019a, 2019b; but also Coutanche, 2019).

⁴¹ The interaction between session, condition, and age group was not significant, but the interaction between session and condition was significant. The competition effect on Day 1 was close to 0 ms in both groups immediately after training.

Results indicated that cued recall was enhanced after 1 week in participants with high vocabulary abilities compared with participants with low vocabulary abilities. However, the improvement after 1 week was less important in the adult group compared with the improvement in both children groups (Experiments 1 and 3). Neighbourhood density interacted with vocabulary abilities, such that participants with high vocabulary abilities learned novel words with one orthographic neighbour better than participants with low vocabulary abilities, suggesting that prior vocabulary knowledge plays an important role in novel word learning.

These results contrast with Henderson et al.'s (2015), who found that novel word learning in children, more than in adults, was dependent on prior vocabulary knowledge. Differences in learning procedures (incidental vs. intentional) may explain this discrepancy and suggest that prior linguistic knowledge and specific task demands might impact novel word lexicalization in a different way for children and adults.

Interim summary. There is some evidence that preexisting phonological schemas (e.g., Havas et al., 2018) and phonotactic patterns (e.g., Fernandes et al., 2009) are crucial to novel word learning and lexicalization. This observation is consistent with the influence of vocabulary skills on novel word learning—higher vocabulary skills may be associated with more robust preexisting phonological/orthographical representations, which may impact novel word learning and lexicalization (e.g., James et al., 2019). More research is needed, however, to clarify the role of vocabulary skills across the life span. There is also some evidence that preexisting semantic schemas impact novel word learning (e.g., Coutanche & Thomson-Schill, 2014; Havas et al., 2018), although the relationship between these and phonological schemas is unclear.

General summary of novel word learning in monolingual/L1 individuals Overall, there is evidence that novel words are initially represented as episodic traces, which are modality specific (e.g., Bakker et al., 2014; Kapnoula & Samuel, 2019). Over time, abstract, lexicalized representations gradually emerge (e.g., Gaskell & Dumay, 2003; Tamminen & Gaskell, 2008). A number of studies have found that after an off-line period, novel words behave like existing words when one considers their interactions with other existing words (e.g., Tham et al., 2015; Wang et al., 2017).

These effects do not seem to depend crucially on explicit novel word knowledge (e.g., Bakker et al., 2014; Dumay & Gaskell, 2012; Tamminen & Gaskell, 2013). Interestingly, lexicalization for novel words associated with a meaning (i.e., more complex representations) may take longer to emerge (e.g., Dumay et al., 2004), as these representations

may conflict with preexisting knowledge in different ways. However, similarity with preexisting schemas may enhance novel word learning (e.g., Havas et al. 2018) and lexicalization (e.g., Coutanche & Thomson-Schill, 2014; Leach & Samuel, 2007).

However, some studies call the role of sleep, which crucial to the CLS account, into question (e.g., Geukes et al., 2015; Lindsay & Gaskell, 2013; Fernandes et al., 2009). The CLS account does not predict that sleep is the only factor that may lead to lexicalization, as interleaving of old and new knowledge may happen during wake. It is, however, unclear how interleaving may happen immediately after exposure. Differences in incidental (statistical learning, fast-mapping) versus intentional learning (phoneme/letter monitoring) may partially explain the differences—many studies inconsistent with the CLS used incidental training paradigms (e.g., Fernandes et al., 2009; Szmalec et al., 2012; although see Kapnoula et al., 2015). These may depend on different mechanisms than intentional learning, which may impact the time course of lexicalization (e.g., Coutanche & Thomson-Schill, 2014).

Moreover, many studies that are inconsistent with the CLS (e.g., Geukes et al., 2015; Kapnoula et al., 2015) did not use lexical decision tasks to assess lexicalization—this suggests that lexical decision tasks, widely used in the literature, may be too coarse a measure to detect subtle, immediate lexicalization effects. It is further unclear how the quality of the initial memory trace impacts lexicalization, or if explicit knowledge is necessary for lexicalization to emerge (e.g., Szmalec et al., 2012; Walker et al., 2019).

Finally, it should be noted that the studies reviewed above were generally unclear about the cover story given to the participants regarding the nature of the novel words. Novel words may have been presented as artificial, as actual words belonging to an unknown language, or as new words in their native language. The cover story, along with the similarity between novel words and existing words in the native language (e.g., syllable structure), may shape participants' expectations and performance, and is a potential avenue for future research.

It is also unclear from these studies how novel word lexicalization proceeds in bilingual speakers. It is possible that L2 word learning is slower than L1 word learning, as L2 schemas are less well-established—a consequence of lower exposure to L2 versus L1. Establishing L2 representations may also be slowed down by inconsistency of new L2 knowledge and existing L1 schemas, at the phonological level, for example. In general, neocortical representations for novel L2 words are thought to emerge later than those for novel L1 words and to be dependent on the hippocampal system for a longer period of time (see Lindsay & Gaskell, 2010). In the next section, we review the handful of studies that have begun to investigate this issue.

The time course of novel word learning and lexicalization in L2 speakers

It is crucial to understand the differences between the monolingual and bilingual lexicon to understand how novel L2 words might be integrated into semantic memory. Experience with multiple languages has been shown to have a profound impact on language representation and processing (for a review, see Palma & Titone, 2020). Bilingualism is characterized by reduced lexical entrenchment—a consequence of reduced absolute exposure with each of the known languages—whereas monolinguals have experience with only one language (Whitford & Titone, 2019). Moreover, as bilinguals are usually more exposed to their first (L1) than to their second (L2) language, lexical quality and lexical access are reduced during L2 processing compared with L1 (for a review, see Whitford, Pivneva, & Titone, 2016; Whitford & Titone, 2019). Finally, there is substantial evidence that bilingual lexical access is nonselective, with representations from both L1 and L2 being activated during language processing (see Palma & Titone, 2020, for a review).

These considerations have two consequences for the study of novel word learning. First, variability in results across monolingual studies might be explained in part by individual differences in bilingual experience. Participants' monolingualism should not be assumed, and bilingual experience should be consistently reported, if not directly studied. Second, L2 word learning and lexicalization might operate differently than L1 word learning. The conclusions of research on bilingual language processing align remarkably well with the predictions formulated by Lindsay and Gaskell (2010). Reduced lexical quality and accessibility might lead to slower integration of novel L2 words into the lexicon. Moreover, individual differences such as age of acquisition, proficiency, exposure, and lexico-phonological characteristics of each language may modulate the pace of sleep-related lexicalization (Lindsay & Gaskell, 2010).

Elgort (2011) investigated meaningful novel word learning in nonnative advanced English speakers (various L1). In Experiment 1, novel words were presented in both their written and spoken form to the participants, along with a definition, an exemplar sentence, and grammatical details. Participants were asked to independently practice the novel form–meaning mappings using flashcards before being tested 1 week after initial training through a primed lexical decision task and a dictation task. In the dictation task, participants listened to novel words and were asked to write down their definition. No priming was evidenced for either trained novel words (e.g., *bunction*–FUNCTION) and existing words (e.g., *junction*–FUNCTION) compared with untrained novel words, suggesting novel word lexicalization.

Experiment 2 revealed the presence of masked repetition priming for trained novel words (e.g., *bunction*–

BUNCTION), similar to the effect found for existing low-frequency words (e.g., *mythical*–MYTHICAL). Experiment 3 revealed that novel trained words, but not novel untrained words, semantically primed existing words. These results, which differ from the results of Qiao et al. (2009), suggest that L2 novel words were integrated in the mental lexicon.

Qiao and Forster (2017) investigated how second-language learners learned meaningful written novel words in a second language. Participants were Mandarin speakers with English as their L2 (intermediate to advanced proficiency). On Day 1, novel words through a word-to-picture matching task, a picture-to-word matching task, and a word-to-definition matching task. Participants were tested on a primed lexical decision task, with novel words serving as primes to existing words or existing words serving as primes to novel words (e.g., *banara*–BANANA, *banana*–BANARA). Training and test were three times over the course of two weeks. Results indicated that novel words primed related existing words (e.g., *banara*–BANANA) even after four training sessions and multiple sleep intervals. Existing words also primed related novel words (e.g., *banana*–BANARA), indicating an absence of prime lexicality effect for existing L2 words as well.

The authors concluded that L2 novel words may be stored primarily in episodic memory and not become lexicalized with training and sleep, contrary to L1 novel words. Moreover, as there was no sign of prime lexicality effect for already known L2 words, it suggests that these words are not fundamentally different from novel L2 words. Alternatively, these effects might arise because postaccess verification processes are slower in L2 compared with L1. When presented with an L2 prime (novel or existing word) followed by an L2 target (novel or existing word), L2 readers may spend more time identifying mismatches (e.g., *banara*–BANANA; *banana*–BANARA). Facilitation would thus occur, as the primes are not recognized as being different from the targets early enough.

Interim summary The two studies reviewed here have contrasted results, with Qiao and Forster (2017) showing no lexicalization of novel L2 words while Elgort (2011) showed a pattern sleep-related lexicalization of novel L2 words similar to monolingual studies (e.g., Tamminen & Gaskell, 2013).

The absence of lexicalization in Qiao and Forster (2017) is consistent with the CLS model adapted to L2 acquisition, which predicts that novel L2 words might depend on episodic memory for a longer time than novel L1 words. Interestingly, the absence of prime lexicality effect for existing L2 words may be explained by reduced lexical quality and/or weaker lexical processing in L2 compared with L1 (see Whitford & Titone, 2019). However, it is unclear why these effects arise, as they could be explained by low L2 proficiency or exposure, or by the important differences between L1 and L2 at the lexical and phonological level. Moreover, as the participants

acquired their L2 late in life, it is unclear whether these conclusions apply specifically to late L2 learners but not to individuals who acquire two languages from birth.

Elgort (2011) showed that novel L2 words were integrated in semantic memory networks after multiple sleep intervals, which is surprising considering the predictions of the CLS model adapted to L2 acquisition. However, it should also be noted that participants were instructed to train independently on novel words before being tested again 1 week after training. No study on monolinguals included this parameter. It is therefore possible that more training is necessary for novel L2 words compared with novel L1 words to be integrated into the lexicon. It should also be noted that participants were more advanced English learners than in Qiao and Forster (2017). It is unclear, however, if differences between L1 and L2 at the lexical and phonological level played a role, as participants' L1 was not controlled for. It is therefore possible that participants benefitted from co-activation from L1 representations that facilitated the integration of L2 novel words in semantic memory networks.

General discussion

In this paper, we reviewed behavioural studies that investigated the effect of sleep on novel word learning and lexicalization. Here, we attempt to link the studies reviewed with theoretical accounts of novel word learning, in particular, with the CLS account. We discuss the studies reviewed in relationship with three important questions: (1) Is there evidence in favor of a dichotomy between episodic and lexicalized representations, and is there a relationship between the two? (2) Is sleep crucial for lexicalization? (3) How important is prior knowledge in the establishment of lexicalized representations?

Is there evidence of a dichotomy between episodic and lexicalized representations, and is there a relationship between the two?

The CLS account posits a dichotomy between episodic memory and semantic memory, which are thought to depend on different brain structures (M. H. Davis & Gaskell, 2009). While episodic memories emerge immediately, the development of abstract, lexicalized representations within semantic memory is thought to be a gradual process. Overall, the studies reviewed here support this distinction between the two systems. Episodic knowledge for novel words, indexed by accurate episodic recognition and/or recall both immediately after novel word exposure and after a delay, is evidenced across multiple studies (e.g., Dumay & Gaskell, 2007; Tamminen & Gaskell, 2013).

Moreover, several studies point out that the emergence of lexicalized representations for novel words—that is,

representations that interact with existing ones—is not immediate (e.g., Gaskell & Dumay, 2003; Henderson et al., 2015). These representations exhibit several characteristics that distinguish them from episodic representations—they are decontextualized, as they have been found to be less dependent on modality or speaker identity (e.g., Bakker et al., 2014; Kapnoula & Samuel, 2019). They do not depend on episodic memory, as there is evidence that their interaction with existing representations is not mediated by awareness (e.g., Dumay & Gaskell, 2012; Tamminen & Gaskell, 2013). These representations are long-lived, even in the absence of further exposure to novel words, and exhibit age of acquisition effects (e.g., Tamminen & Gaskell, 2008).

Finally, there is also evidence of a negative relationship between episodic knowledge and lexicalization effects (e.g., Bakker et al., 2014; Coutanche & Thomson-Schill, 2014; Leach & Samuel, 2007; Tamminen & Gaskell, 2013). This suggests that episodic knowledge may not be helpful for novel word lexicalization, and that it may even hinder it. On a related note, it is unclear how necessary an episodic memory for the novel word is. The CLS assumes that episodic memories are formed immediately upon exposure, but several studies reviewed here (e.g., Szmalec et al., 2012; Fernandes et al., 2009; Coutanche & Thomson-Schill, 2014) have found that incidental learning procedures can immediately produce lexicalized representations (although see Sobczak et al., 2019). Currently, to the best of our knowledge, no consensus has been reached on the topic.

Is sleep crucial for lexicalization, and if so, how?

One of the CLS account's predictions is that off-line consolidation plays a crucial role in the emergence of neocortical representations for novel words, in that it allows novel words to become interleaved with existing lexical representations in the mental lexicon of an individual. Sleep is an ideal state for this interleaving to occur, because the cognitive system is not actively processing novel information (McClelland et al., 1995). Specifically, hippocampal representations are posited to be reactivated during slow-wave sleep and to prime related neocortical representations. However, the development of neocortical networks may occur during wake through interleaved exposure to existing and novel words (e.g., McClelland et al., 1995).

Many studies reviewed here have found evidence of lexicalization after, not before, a sleep interval (e.g., Bakker et al., 2014; Dumay et al., 2004; Wang et al., 2017). As many studies contrast groups of participants tested after a time delay including or not including a sleep interval, many authors have concluded that sleep, not time passing, as the crucial factor underlying lexicalization. Moreover, the role of sleep may still partially be explained by circadian rhythm effects, and/or by uncontrolled or particular intervening activity for participants

that are retested without a sleep interval. Furthermore, most of the studies reviewed here do not control for time-of-day confounds, such that it is possible that participants assigned to evening groups experienced higher levels of fatigue than participants assigned to morning groups. If this is true, then higher performance after a sleep interval for the evening group is potentially driven by lower performance on the first test the evening before.

Related to this issue is the question of task-related fatigue. Long experimental sessions involving multiple repetitions of same items may generate a reactive inhibition effect—performance worsening can accumulate when training is continuous, such that participants do not improve as much as expected, but improve after a break (e.g., Pan & Rickard, 2015). The effect of sleep identified in the studies reviewed here might therefore be explained, at least partially, by the dissipation of this reactive inhibition effect (see Nemeth, Gerbier, & Janacek, 2019, for a similar argument). It should be noted, however, that in many of the studies reviewed here, participants were tested only once (on novel words learned before and after a sleep interval, e.g., Tamminen & Gaskell, 2013). Task-related fatigue may not be so relevant when

Fig. 1 The complementary learning system model, adapted from McClelland et al. (1995). Arrows are labeled with model parameters: $S_h(0)$ and $S_c(0)$ refer to the strength of the hippocampal and neocortical traces resulting from initial exposure to a stimulus; C refers to the rate of consolidation, and D_h and D_c refer to the rate of decay in the hippocampal and neocortical systems, respectively

Fig. 2 An adapted visualization of the revised complementary learning systems model, based on McClelland (2013), McClelland et al. (2020), and conclusions of the current review. As in the original version of the model, arrows are labeled with model parameters: $S_h(0)$ and $S_c(0)$ refer to the strength of the hippocampal and neocortical traces resulting from initial exposure to a stimulus; D_h and D_c refer to the rate of decay in the hippocampal and neocortical systems, respectively, and $C(p)$ refers to the rate of consolidation, modulated by the degree of prior-knowledge inconsistency

considering this kind of design. Finally, because we only reviewed behavioural studies here, it is difficult to determine whether sleep only plays a passive role of protecting newly formed memories against interference, or whether it activates specific neurobiological processes that directly impact consolidation (see Ellenbogen, Payne, & Stickgold, 2006; Nemeth et al., 2019; Rasch & Born, 2013; Yonelinas et al., 2019).

Nap study designs may help in assessing the role of sleep and disentangle sleep from circadian confounds. Of note, however, the correlations between sleep physiology and memory consolidation are often not found reliably across studies (see Nemeth et al., 2019). The investigation of circadian rhythm effects, as an important predictor rather than a source of noise, is also a potentially fruitful avenue. Circadian rhythm may interact with training characteristics—implicit training procedures in the evening have been shown to be associated with higher performance, while explicit training procedures in the morning are associated with higher performance (Himmer et al., 2017; see also May, Hasher, & Foong, 2005, on the variation of circadian schedules across implicit and explicit retrieval tasks).

Finally, several studies reviewed here call the mechanistic role of sleep into question, which suggest a richer variety of time courses of lexicalization. The impact of sleep seems to vary across a variety of factors, including characteristics of training (incidental vs. intentional). For example, Fernandes et al. (2009) found evidence of immediate lexicalization for novel words learned through a statistical learning paradigm. Similarly, fast mapping may promote rapid lexicalization (e.g., Coutanche & Thompson-Schill, 2014; but see also Cooper, Greve, & Henson, 2019a, 2019b). This contrasts with the results of many studies that have found evidence of

delayed lexicalization using more intentional learning paradigms, such as a phoneme-monitoring procedure (e.g., Dumay & Gaskell, 2012). The methods used to assess novel word lexicalization may also play a crucial role—Geukes et al. (2015) found evidence of immediate lexicalization using a Stroop task, a task that is not typically used in the literature reviewed. Interestingly, interleaved training and test have also been found to promote the emergence of lexicalized representations in the absence of a sleep interval—exposure to existing representations, through a lexical decision task, for example, may crucially induce plasticity and promote novel word integration into the mental lexicon (e.g., Lindsay & Gaskell, 2013). Sleep can therefore be thought of as a sufficient, but not necessary condition for lexicalization (Lindsay & Gaskell, 2013). The presence of opportunities for interleaving may partially explain the discrepancy between the results of the studies reviewed here (although see Kapnoula et al., 2015). It should also be noted that lexical decision tasks may be too coarse a measure to assess lexicalization, especially when competition effects are small, which may explain the discrepancies observed between studies (see Kapnoula et al., 2015).

What is the role of prior knowledge in the establishment of novel word representations?

Within the CLS account, consistency with existing representations (i.e., schemas) may facilitate the integration of new knowledge in memory networks, by activating phonological/orthographical representations in the language (e.g., English). Inconsistency—as in the case of novel words that do not resemble existing words—may slow down this process (see McClelland, 2013). This distinction is thought to prevent catastrophic interference.

There is some evidence that preexisting phonological schemas are crucial to novel word learning and lexicalization. For example, consistency with native language phonology has been found to enhance novel word learning, while novel words that are inconsistent with native language phonology have been found to be lexicalized more slowly (e.g., Havas et al., 2018). Similarly, consistency with native language phonotactic schemas and transitional probabilities has been found to enhance lexicalization (e.g., Fernandes et al., 2009). It is also interesting to many studies that have found evidence of lexicalization after sleep (e.g., Dumay & Gaskell, 2012; Gaskell & Dumay, 2003; Henderson et al., 2015; Wang et al., 2017) were focused on words based on existing words (e.g., *cathedruce*)—words that may benefit from the activation of a preexisting phonological/orthographical schema.

Fewer studies have investigated the lexicalization patterns for words that were not based on existing words—words that do not benefit from a preexisting phonological schema in the native language. Leach and Samuel (2007) found evidence of

weaker lexicalization for such words, except when these were associated with a meaning. Providing a meaning to the word may allow for the activation of preexisting semantic schemas, and thus facilitate the integration of novel words. In contrast, novel words based on existing words have been found to be lexicalized more slowly when they are associated with a meaning than when they are not (e.g., Dumay et al., 2004). When a preexisting phonological schema exists, associating a meaning with the novel form may increase the risk of eliminating existing mappings, leading to slower lexicalization.

However, the relationship between consistency with preexisting phonological schemas and consistency with preexisting semantic schemas is unclear. Coutanche and Thomson-Schill (2014) found evidence of accelerated lexicalization for novel words based on English words using fast mapping. Presenting both an unfamiliar referent for the novel words and a familiar referent the participant has to actively reject may promote the activation of the preexisting semantic schema for the familiar referent. However, Havas et al. (2018), who used simple picture–word pairings, found superior memory performance for novel words consistent with native language phonology when these were paired with familiar objects, compared with unfamiliar objects. More research is needed to understand the relationship between phonological/orthographical and semantic consistency and its impact on novel word lexicalization.

The investigation of individual differences in novel words lexicalization may be a particularly fruitful avenue for resolving some of the inconsistencies noted above. For instance, high vocabulary skills and/or reading fluency may be associated with more robust preexisting phonological/orthographical representations, which may in turn impact novel word learning. Only two of the studies reviewed here have investigated this issue, and their findings are not consistent with one another. Henderson et al. (2015) found that high expressive vocabulary was correlated with both increased explicit memory of novel words and increased competition with base words in children, not in adults. However, James et al. (2019) found that high expressive vocabulary was a better predictor of higher explicit memory for novel words in adults than in children. Differences in experimental design may explain the discrepancy between these two studies—it is possible that more naturalistic learning contexts, such as the one in Henderson et al. (2015), may provide participants with fewer opportunities to link novel words to existing words, compared with more explicit training procedures, such as the one in James et al. (2019). Explicit training conditions might promote the use of explicit strategies to link novel words with existing words. Adults, with larger vocabulary, compared with children, might therefore maximally benefit from explicit training procedures.

More broadly, as suggested by James et al. (2019), prior vocabulary knowledge benefits might be driven by lexical

quality (Perfetti, 2007), which differs between children and adults. Higher quality representations may support word learning by providing robust schemas, while lower quality representations might provide weaker support. Interestingly, lexical quality might also vary considerably across among L2 speakers with different levels of proficiency. The effect of prior vocabulary knowledge might therefore be particularly enhanced among L2 adult speakers. This hypothesis, along with others, has yet to be tested. For example, individual differences in phonological awareness might influence how novel spoken words are learned and integrated in the mental lexicon. In general, a focus on the influence of individual differences in novel word learning is desirable for future research.

Investigation of sleep-related lexicalization of novel words into the L2 lexicon may also help understanding the role of preexisting schemas. Few studies so far have investigated novel L2 words lexicalization. The two studies on that topic that we reviewed here have found very different results. Elgort (2011) found that nonnative advanced English speakers exhibited sleep-related lexicalization of novel words consistent with English phonology in three primed lexical decision tasks, a finding consistent with prior research (e.g., Tamminen & Gaskell, 2013). In contrast, Qiao and Forster (2017) found that English L2 speakers (L1 Mandarin) did not exhibit lexicalization for novel words consistent with English phonology after a sleep interval. Instead, both trained and untrained novel word forms were shown to prime existing words. Existing L2 words were also found to prime other existing L2 words, which departs from what is classically found for monolingual speakers (e.g., C. J. Davis & Lupker, 2006). The authors concluded that novel words were stored in episodic memory even after an interval of sleep and were not integrated into the mental lexicon. They also argued that the L2 lexicon might be distinct from the L1 lexicon, as existing L2 words did not exhibit the behaviour of existing words observed in monolingual studies.

It is possible that participants' characteristics might play a role in the observed discrepancy—participants in Elgort (2011) were more advanced, with potentially higher vocabulary skills, than participants in Qiao and Forster (2017). Moreover, phonological distance between L1 and L2 may impact how novel L2 words are consolidated. Because participants in Elgort (2011) varied in terms of L1, it is unclear how L1–L2 similarities at the phonological and/or lexical level might play a role in novel L2 words sleep-related lexicalization. In particular, it is possible that bilingual participants of closely related languages, phonology-wise, might show patterns of lexicalization that differ from bilingual participants of distant languages (such as the participants in Qiao & Forster, 2017).

Overall, very few studies have considered the integration of novel L2 words in the mental lexicon, although the framework of a complementary learning systems account of L1 and L2 word learning was outlined a decade ago (see Lindsay & Gaskell, 2010). Interestingly, some studies in the second language

literature (e.g., Godfroid et al., 2017; Pellicer-Sánchez, 2016) have shown that native and nonnative English speakers exhibit similar reading patterns on novel words, and that reading patterns are correlated to learning outcomes in both native and nonnative English speakers. A bilingual advantage for novel word learning has also been identified in the literature (see Hirosh & Degani, 2018, for a review). However, as these studies did not investigate the interaction of novel words with existing L2 words, this could be a fruitful avenue for future studies.

Moreover, no study to our knowledge has systematically investigated sleep-related lexicalization in the L1 and L2 lexicon in bilingual participants. It would be particularly interesting to contrast the words that are consistent with the native language, as well as words consistent with a known second language, in order to refine our understanding of the impact of preexisting schemas. Studying novel word sleep-related lexicalization within bilingual participants might allow researchers to investigate whether L1 and L2 lexicons are separated or integrated and might also highlight the role of individual differences in L2 exposure or proficiency in novel word learning.

Thus, moving away from monolingual samples and focusing on individual differences in sleep-related lexicalization might enrich current models of human memory. In particular, studying bilingual participants might help refine our understanding of the conditions under which novel words become lexicalized. Finally, it might allow a better understanding of the organization of human declarative memory more generally.

Overall, the empirical results reviewed here bring support to the hypothesis that neocortical learning is not necessarily slow, but that it is prior-knowledge dependent (McClelland, 2013, see also van Kesteren et al., 2013; van Kesteren, Fernandez, Norris, & Hermans, 2010). Initial storage may therefore occur either in the form of a hippocampal memory trace ($S_h(t)$) the hippocampal system, if novel knowledge is inconsistent with prior schemas, or in the form of a neocortical memory trace, if it is consistent with prior schemas ($S_c(t)$). With this new “division of labor,” novel words that fit with L1 schemas are at an advantage when it comes to novel word learning, as they may be initially stored in the neocortical system. In contrast, novel L2 words, because they do not fit with prior, well-established L1 schemas, may be initially stored in the hippocampal system (see Lindsay & Gaskell, 2010).

Furthermore, it is possible that the degree of prior-knowledge inconsistency may impact the consolidation rate (C_p)—substantial crosstalk between hippocampal and neocortical systems might persist for a longer time to overcome difficulties in integrating novel words greatly inconsistent with preexisting schemas (see van Kesteren et al., 2010), such as novel L2 words. In Fig. 2, we propose an adapted visualization of the CLS model reflecting these hypotheses, in line with recent theoretical and computational work on the CLS model (McClelland et al., 2013; McClelland et al., 2020) and the conclusions of the current review.

Conclusion

In this paper, we reviewed a number of studies that investigated long-term retention of novel words through behavioural techniques. We first described the different human memory systems, then the process of memory consolidation, and the various models of memory consolidation. We also discussed the role of sleep and the correlations that have been found between sleep physiology and memory consolidation. We reviewed behavioural studies that have investigated novel words sleep-related lexicalization in monolingual/L1 samples, then the few studies that have investigated novel L2 words sleep-related lexicalization in nonnative speakers. Overall, many studies are consistent with a mediating role of sleep in the gradual emergence of novel word representations, although several studies suggest a richer variety of time courses for novel word lexicalization, potentially reflecting prior-knowledge consistency. Individual differences in prior lexical knowledge also seem to play a role in novel word lexicalization. Therefore, novel word sleep-related lexicalization in the L2 lexicon represents a desirable avenue for future work that has the potential to enrich our

understanding of both vocabulary development and more general models of human memory consolidation.

In line with prior research (e.g., M. H. Davis & Gaskell, 2009), we conclude that novel word learning has the potential to inform memory research. For instance, novel word learning allows one to build upon the wealth of psycholinguistic/neurolinguistic evidence to understand how familiar words are processed (e.g., the priming literature), and use similar paradigms to study how novel words are added to the lexicon. Word learning is also interesting in that words are complex memory representations—knowing a word entails knowing how it sounds and what it looks like (perceptual representation), how it is pronounced or signed (procedural representation), and what it means (semantic representation). Knowing a word also entails knowing in which grammatical context or in which social context one should use it. Word learning therefore provides the researcher with a unique opportunity to investigate the development of memory representations across multiple systems.

Open practices statement There is no data or material associated with this review paper. Because this paper does not present empirical work, there was no preregistration.

Appendix A

Table 1. Summary table

Authors (year)	Population	Novel words	Tests	Key results	Consistency with CLS
Gaskell & Dumay (2003)	Native English speakers	Based on English words (final deviation), form-only	2AFC ^a LDT ^b PD ^c	Good recognition Postsleep competition (Exp. 1: Days 4 and 5; Exp. 2: Day 8)	✓
Dumay et al. (2004)	Native English speakers	Based on English words (final deviation), form-only vs. meaningful	2AFC FA ^d FR ^e PLDT ^f PD	Improved postsleep recognition Delayed competition for meaningful vs. form-only (Day 8 vs. Day 2) Immediate facilitation form-only words	✓
Bowers et al. (2005)	Native English speakers	Based on English words (1 letter deviation), form-only	SDT ^g	Postsleep competition Training increases competition	✓
Dumay & Gaskell (2007)	Native English speakers	Based on English words (final deviation), form-only	2AFC FR PD	Similar recognition and recall in no-sleep and sleep group Competition only in sleep group Positive correlation recall and delayed competition	✓
Leach & Samuel (2007)	Native English speakers	Not based on English words, form-only and meaningful	3AFC WIN ^h PRT ⁱ PLT ^j	Gradual improvement recognition Postsleep phonological learning depends on training characteristics	✓
Tamminen & Gaskell (2008)	Native English speakers	Based on English words (final deviation), form-only	2AFC LDT	Postsleep, long-lasting competition (8 months) Order of acquisition effect	✓
Fernandez et al. (2009)	Native Portuguese speakers (?)	Based on Portuguese words (final deviation), form-only	2AFC LDT	Immediate competition, strengthens post-sleep Competition depends on novel word “wordlikeness”	✗
Qiao et al. (2009)	Native English speakers	Based on English words (1 letter deviation), form-only	MPLDT ^k PLDT	Immediate and postsleep facilitation Postsleep priming effects similar to existing words	✗ ✓

Table 1. (continued)

Authors (year)	Population	Novel words	Tests	Key results	Consistency with CLS
Elgort (2011, Exp. 1)	Non-native English speakers (various L1)	Based on English words (1 letter deviation), meaningful	MPLDT	Evidence of L2 consolidation	
Dumay & Gaskell (2012, Exp. 1)	Native English speakers	Based on English words (final deviation vs. fully-embedding), form-only	2AFC FR PD WS ¹	Smaller postsleep recognition and recall for fully embedding competitors Immediate facilitation and postsleep competition for fully embedding competitors	✓
Szmalec et al. (2012)	Native (?) Dutch speakers	Based on Dutch words (1 syllable deviation, form-only)	LDT PD	Similar competition sleep vs. no sleep	✗
Lindsay & Gaskell (2013)	Native English speakers	Based on English words (final deviation), form-only	SC ^m FD ⁿ LDT	Improved postsleep recognition Competition depends on exposure to both existing and novel word (interleaving) more than on sleep	✗
Tamminen & Gaskell (2013)	Native English speakers	Not based on English words (final deviation), meaningful	Recall MPLDT	Recency effect on recall Priming only for remote novel words No effect of recall on priming	✓
Bakker et al. (2014)	Monolingual Dutch speakers	Based on Dutch words (final deviation), form-only	FR 2AFC PD SDT	Postsleep competition across modalities Same training/test modality = earlier emergence of competition	✓
Coutanche and Thomson-Sc-hill (2014)	Native English speakers	Based on English words (1 letter difference), meaningful	FR 3AFC SDT MPLDT	Immediate and postsleep improved recall/recognition in explicit encoding vs. fast-mapping condition Immediate and postsleep competition in FM (not EE) group Semantic priming after sleep only in FM (not EE) group	✗
McGregor (2014)	Native (?) English speakers	Based on English words (1 letter difference), meaningful	2AFC WA ^o FR	No differences sleep vs. no sleep Forcing novel word retrieval shortly after learning disrupts subsequent recognition speed, but improved recall accuracy	✓
Geukes et al. (2015)	Native German speakers	Not based on German words, meaningful (color)	Stroop task	Immediate and postsleep Stroop congruency effects Effects depends on interleaving	✗
Henderson et al. (2015)	Native English speakers	Based on English words (final deviation), meaningful	PD Cued recall 2AFC Definition task WASI-II	Postsleep competition effects Positive correlation vocabulary skills and postsleep competition in children, but not adults	✓
Kapnoula et al. (2015)	Native English speakers	Based on English words (1 phoneme difference), form-only	VWPP ^p with spliced stimuli	Immediate competition, no sleep or interleaving necessary Competition independent from training characteristics	✗
Tham et al. (2015)	Monolingual English speakers	Mandarin characters, meaningful	2AFC	Immediate and postsleep semantic congruity effects Postsleep size congruity effects	✓
Himmer et al. (2017)	Native German speakers	Very low-frequency German words, meaningful	3AFC	FM < EE Sleep and absence of sleep impacted EE more than FM group Circadian rhythm effects: FM group better in evening, EE group better in morning	✗
Qiao & Forster (2017)	English-Chinese bilinguals	Based on English words (1 letter difference), meaningful	PLDT	Immediate and postsleep facilitation No evidence of L2 consolidation	✗
Wang et al. (2017)	Native English speakers	Based on English words (1 letter difference), form-only	SCT FR	Postsleep competition Post sleep improved recall	✓
Havas et al. (2018)	Native Spanish speakers	Based on Spanish words (final deviation) or real Hungarian words, meaningful	4AFC PLDT	Spanish-consistent > Hungarian Improved postsleep recognition for Hungarian words No priming effects	✓
James et al. (2019)	Native English speakers	Not based on English words, meaningful	Cued recall 4AFC WASI-II	Improved postsleep recall and recognition for participants with high vs. low vocabulary skills High vocabulary skills = improved recall of novel words with 1 orthographic neighbour	✓
Kapnoula & Samuel (2019)	Native Spanish speakers	Not based on Spanish words, meaningful	VWP	Fixation speed of the referent impacted by speaker–picture congruency during training Postsleep reduced congruency effect No awareness of speaker–picture association	✓

Table 1. (continued)

Authors (year)	Population	Novel words	Tests	Key results	Consistency with CLS
Sobczak & Gaskell (2019)	Native English speakers	Based on English words (1 syllable difference), form-only	PD Cued recall 2AFC	No postsleep competition after Hebb repetition learning task (vs. phoneme-monitoring) Improved postsleep recall and recognition in phoneme-monitoring group	✗
Walker et al. (2019)	Monolingual English speakers	Based on English (1 letter difference), form-only	FR 2AFC SDT	Improved postsleep recall Immediate and postsleep competition Training intensity effect on post and postsleep performance	✗

^a Alternative Forced-Choice task (2 choices)

^b Lexical Decision Task

^c Pause-detection task

^d Free Association task

^e Free Recall

^f Primed Lexical Decision Task

^g Semantic Decision Task

^h Word-in-noise task

ⁱ Phonemic restoration task

^j Perceptual learning task

^k Lexical decision task with masked primes

^l Word-spotting task

^m Stem completion task

ⁿ Familiarity decision task

^o Word association task

^p Visual world paradigm

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