Language abstraction: Consolidation of language structure during sleep

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Abstract

Recent research on how sleep influences cognitive processes has pointed to the potential role of sleep in the consolidation and generalisation of information across a range of tasks, including some language learning tasks (i.e., Gómez, Bootzin, & Nadel, 2006; Wagner, Gais, Haider, Verleger, & Bom, 2004; Walker, 2005). The current study investigated the role of sleep in grammatical category generalisation by testing participants for categorical knowledge 12 hours after initial training. Participants were tested on their categorisation of the training words and also on their ability to generalize to novel, but consistent category words. The sleep group received training at 9pm and the wake group at 9am. Only the sleep group was able to abstract the general category characteristics to the novel category words which implies a domain general abstraction mechanism may be influential in language acquisition.

Introduction

The child's language environment provides an immensely rich source of information that can contribute to the development of structure at the word level (Saffran, Aslin, & Newport, 1996) and to the development of grammatical categories (Redington, Chater, & Finch, 1998) and syntactic constraints (Bod, 2007). From a sea of sounds (Saffran, 2001), the child must learn where words begin and end ***in*** continuous speech, and the child must also learn the constraints on the relations ***between*** words, as described by grammatical structure. One of the central issues in the cognitive science of language over the last 50 years is to determine the extent to which the language environment triggers innately-specified, domain-specific processing (Chomsky, 2006; Pinker, 1991), and the extent to which sufficient information is present within the signal to provide structure via general-purpose learning mechanisms (Conway & Christiansen, 2005; Saffran, 2002).

Chomsky (1965, 1980) proposed that the linguistic input that a child is exposed to provides insufficient information to adequately constrain the actual grammar of the language that the child develops (Gold, 1967). For instance, children are unlikely to be exposed to instances of auxiliary-fronting (e.g., converting "the dog that is sleeping is grey" to a question format: "is the dog that is sleeping grey" by moving the correct auxiliary verb). The debate over whether general-purpose learning mechanisms can provide sufficient, indirect constraints to distinguish between grammatical versus ungrammatical constructions is a matter of current contention (see, e.g., Messer et al., 1995; Reali & Christiansen, 2005).

However, before positing specific language-learning mechanisms or innately-specified linguistic structure, it is important to do full justice to the potential richness of general purpose learning mechanisms for the acquisition of language structure. There are many candidates for studies showing the great potential of linguistic input (Monaghan, Christiansen, & Chater, 2007) and the versatility of general learning mechanisms that can generate structure from the language itself (e.g., Reali, Christiansen, & Monaghan, 2003). In the latter study, a simple recurrent network was trained to learn the patterns of associations between distributional and phonological cues for categorising grammatical categories in speech. So, a fundamental question for language acquisition research is what are the range of general purpose learning mechanisms available to the language learner, and how do they apply to language input?

There is accumulating evidence that there are critical qualitative distinctions in the effects of learning new material when assessed ***before*** compared to ***after*** sleep, and specifically that sleep may facilitate abstraction and generalisation in a range of tasks (e.g., Fischer, Drosopoulos, Tsen, & Born, 2006; Gómez, Bootzin, & Nadel, 2006; Wagner, Gais, Haider, Verleger, & Born, 2004). Although only a few sleep studies have used linguistic tasks, the underlying structures and features of the stimuli used in many of these studies are strikingly similar to the critical features of natural and artificial languages. The current study advances the established field of language learning studies by making use of innovative recent methods for investigating the cognitive influences of sleep on complex learning. We contend that sleep elicits critical general purpose learning that is important for the process of language acquisition.

Sleep Consolidation and Qualitative Changes in Learning

Sleep has been found to play a pivotal role in memory consolidation, both in terms of declarative and procedural memory, as well as being implicated in brain plasticity for storage (see Walker, 2005 for a review). Increases in perceptual skills and in explicit knowledge about complex tasks has also been associated with sleep (Fischer, Drosopoulos, Tsen, & Born, 2006; Wagner, Gais, Haider, Verleger, & Born, 2004). Wagner et al. (2004) conducted a study to test learning of abstract structure in strings of digits, where the last three digits were the second, third and fourth digits in reverse order (e.g. 1914419). After an eight hour interval that included sleep 59.1% of the participants "gained insight" into the underlying pattern, compared to only 22.7% who did not sleep. Fischer et al. (2006) found a similar result with a task in which participants simply had to press a key to match where a star appeared on screen as quickly as possible. However, a probabilistic finite state grammar controlled the order in which the stars appeared onscreen; only after sleep were participants able to show any explicit knowledge of this implicitly learned grammar. That is, they displayed a qualitative change in the representation of the task enabling explicit access to the implicitly learned structure.

Yet, a potential confound in these studies is that the wake group is exposed to more stimulation and experiences than the sleep group, which may interfere with learning. However, Gais, Mölle, Helms, and Born (2002) compared an associative word pair learning task with a non-learning task (counting curved letters) and the results indicate that only the learning task was associated with an increase in the density of sleep spindles (rhythmic activity between 12 to 14 Hz lasting at least .5 seconds, associated with neuronal plasticity, (Fogel, Nader, Cote, & Smith, 2007) in Stage 2 sleep. Additionally, sleep spindle density correlated significantly with the number of word pairs correctly recalled, indicating that sleep spindles are directly involved in the consolidation of the word pair information. Furthermore, Marshall, Helgadóttir, Mölle, and Born (2006) found that boosting slow wave sleep oscillations (through stimulation via external electrodes) improved memory on a paired associate word task. Specifically, the slow wave sleep stimulation was shown to influence both slow oscillation activity and slow frontal spindle activity, but not fast frontal spindle activity. These studies provide converging evidence that sleep (and perhaps particularly spindle activity) leads to a qualitative shift in the way learned material is represented.

Sleep Consolidation and Language Acquisition

The influence of sleep on qualitative shifts in language acquisition has recently been investigated in several language-oriented tasks. Dumay and Gaskell (2007) studied the effect of sleep on word learning. Participants were trained on novel words and were tested after a 12 hour interval (following sleep or wakefulness) on whether the word had been fully linked into the mental lexicon (in terms of whether it interfered with the identification of previously known words). New words only became a part of the lexicon after sleep. The effect of sleep on the generalisation of phonemes from synthesised speech was studied by Fenn, Nusbaum, and Margoliash (2003). After a synthesised speech listening phase, adult participants were tested on novel examples of the phonemes. After 12 hours of wakefulness participants' ability to correctly identify the synthesized phonemes deteriorated but after a further 12 hours that included sleep the ability to correctly identify the phonemes returned to immediate post training levels.

Gómez, Bootzin, and Nadel (2006) also tested effects of sleep on generalisation in language learning, but using a grammatical structure learning task for an artificial language. Fifteen month old infants were trained on speech comprised of non-adjacent dependencies consisting of three word sequences in which the first word perfectly predicted the third word. Four hours after training the infants were played sequences that were either consistent or inconsistent with the training language. Infants that had slept between training and testing demonstrated a preference for sequences that had the same form as the first sequence they had heard during testing, whereas infants that had not slept did not indicate this preference. This result suggests that the abstract structure of the grammar was consolidated during sleep, even though no systematic preference was shown for either consistent or inconsistent items.

Studies of Grammatical Categorization

The assignation of words to grammatical category roles is a necessary precursor to producing interpretable phrases in language production. In acquiring grammatical categories, language learning may be assisted by the distributional, or co-occurrence, information from within speech (Redington, Chater, & Finch, 1998), as well as coherent phonological information of words within these categories (i.e., nouns sound more like other nouns than they do to verbs, Monaghan, Chater, & Christiansen, 2005).

Grammatical categorisation was studied in an artificial language by St. Clair (2007), who investigated whether distributional information from high-frequency nonsense words, similar to function words, helped form categories of nonsense words with adult participants within artificial languages[1]. Participants were either exposed to a two category language with both phonological and distributional cues to category membership or simply distributional information and were later tested with a similarity task whether the participants could differentiate between correct or incorrect distributional cue/category word pairings. It was found that when phonological information cohered with the distributional information, learning of the categories to which words belonged was observed. However, when there were only distributional cues available to guide categorisation only very high frequency category words were categorised; lower frequency words were not. Thus, categorisation of words occurred only when there were both

[1] Studies of language acquisition using artificial languages have investigated both adult and infant participants, and have typically found similar sensitivities in both groups (e.g., Saffran, 2001, 2002).

phonological and distributional cues, a result coherent with other artificial language studies of categorisation (Cassidy & Kelly, 1991, 2001).

However, it was not clear from this study whether participants learned generic categories or whether the learning was restricted to the particular words heard during training. Thus, it has not yet been established whether participants simply learned particular instances or whether more general characteristics of the category were acquired, which could potentially integrate new category members. The results from Gómez et al.'s (2006) study suggest that sleep may aid in the abstraction beyond specific instances to abstract structures.

The current experiment investigated the effect of sleep on grammatical categorisation, specifically looking at whether there is a qualitative change in the representation of the known category words as well as the integration of new category words. In order to test for this change, participants were tested both on the category words they were trained with and also with novel category words that shared characteristics of the trained category words was varied to determine whether any potential influence of sleep on the novel words was mediated by frequency. If sleep differentially influenced high or low frequency words, it may be that the novel category words elicit quantitatively and not qualitatively different responses.

Experiment: The Effect of Sleep on Category Abstraction

Method

Participants Ten University of York undergraduate and postgraduate students participated in this study, five in the sleep condition and five in the wake condition. All participants were native English speakers and were either paid £5 or received course credit. The sleep participants reported an average of 7 hours 25 minutes sleep during the intervening night (range 6 h. 30m. to 7 h. 45 m.) while the wake participants reported no sleep between initial exposure to the language and the testing phase.

Stimuli and Materials The artificial language used was an adapted auditory version of Valian and Coulson's (1988) written language. There were 12 category words in the language divided equally into two categories, A and B. Each category had a specific marker word that reliably co-occurred with each category word. Each category A word always co-occurred with the marker word ***a***, and each category B word always occurred with the marker word ***b***. In Valian and Coulson's (1988) study the marker word always occurred before the category word, however, due to better category learning from succeeding marker words (St. Clair & Monaghan, 2005), we constructed the language such that marker words occurred immediately after the category words. Thus, the general structure of the language was ***AaBb***. Category words appeared equally often in first and second position. Half of the category words were of high frequency and occurred twice as often as the low frequency category words.

Table 1: High and low frequency and novel category words

Type	*Category A*	*Category B*
High	/twind/	/fɔθ/
	/dɹƐŋ/	/vɒz/
	/kIImp/	/sutʃ/
Low	/gwƐmb/	/zɔdʒ/
	/prink/	/θɒʃ/
	/bIInt/	/ʃuf/
Novel	/pIImt/	/fɔdʒ/
	/grImd/	/zuθ/
	/kwƐŋ/	/tʃɔz/
	/plƐmt/	/dʒuv/

In addition to the distributional cues to category provided by the marker words, there were consistent phonological cues that differentiated the two categories of words. Category A words contained consonant clusters at the onset and offset, rounded low vowels, nasals and stops. Category B words had no consonant clusters, and contained unrounded high vowels and fricatives. Table 1 lists phonetic transcriptions of the words.

In the first test, participants were given a two alternative forced choice (2AFC) task, where one test sentence that conformed to the language's regularity (***AaBb***; compatible) was paired with a test sentence that contained incorrect category word-marker word pairings (***AbBa***; incompatible). There were 16 items. The compatible sentences did not occur in the training session.

The second test session had the same format, but sentences contained novel category words (A' and B') which had the same phonological properties as either the category A or B words. There were eight 2AFC test items in this test session. These items tested whether the general phonological structure of the categories had become associated with the individual marker words allowing the participants to generalize beyond the category words in the training session to novel, but phonologically consistent category words. The phrases with marker word ***a*** (***A'a*** or ***B'a***) were equally likely to occur in the first and second positions. In each 2AFC item there were four unique category words, so no category word was repeated in a set. The pairings of category words per individual test sentence was counterbalanced.

The language was synthesized with the Festival Speech Synthesizer (Black, Clark, Richmond, King, & Zen, 2004) using a monotone male British English voice. Headphones were used to deliver the stimuli presented on a desktop testing computer using E-Prime.

Procedure There were two experimental sessions separated by 12 hours. The sleep group was trained at 9pm and tested at 9am, thus including a night's sleep intervening between training and testing. The wake group was trained at 9am and tested at 9pm and were instructed to not sleep during the intervening daytime hours (Figure 1).

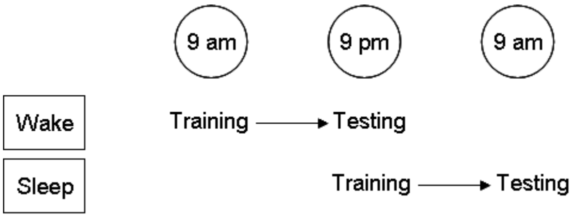

Figure 1: Diagram of the experimental design.

During the training session, the participants were told that they were to listen to a made up language and that they would be tested on their "knowledge of the language" during the second experimental session. They first heard all the words in the language as a familiarization to both the words and the synthesized speech. The training session then began where they heard 18 training sentences repeated 32 times each in a random permuted order. The training lasted approximately 20 minutes. After training, the participants in the sleep condition were told to note approximately when they went to sleep and woke up and the wake group were told to refrain from sleep before the testing session 12 hours later. We did not test learning immediately after training to avoid interference effects due to exposure to both conforming and non-conforming sentences during the test.

During the test phase, participants were instructed that they would hear pairs of sentences that were not presented in the training session and that half of these sentences were similar to the artificial language and the other half were dissimilar. They had to indicate which sentence they thought was "most similar" to the artificial language. The second test phase that included the novel, but phonologically consistent, category words included the same instructions; the participants were told that there would be novel nonwords but that one sentence is similar to the training language and the other is dissimilar.

Results

A mixed ANOVA was conducted with frequency (high and low) as the within subjects factor and condition (wake or sleep) as the between subjects factor. The proportion of choosing the correctly paired category/marker word option was the dependent variable, but only the trained word data was included as, by definition, there were no frequency differences in the novel category words. There were no significant main effects of frequency or sleep condition, both $F < 1$, nor a significant interaction between the two terms, $F(1,8) = 1.64$, $p = .24$. For all subsequent analyses the two frequency groups were combined.

A second mixed ANOVA was conducted with test sentence type (trained or novel category words) as the within subjects factor and condition (wake or sleep) as the between subjects factor. The proportion of choosing the correctly paired category/marker word option was the dependent variable. The results are shown in Figure 2.

There were no significant main effects of test sentence type or condition, $F(1,8) = 2.76$, $p = .14$ and $F < 1$, respectively. However, the interaction between these factors was significant, $F(1,8) = 7.89$, $p < .05$, $\eta^2 = .50$. This interaction was investigated with pairwise comparisons. It was found that there was no difference between the sleep and wake conditions ($p = .43$) with the trained category word test items. However, with the novel category word test items the sleep condition was much more accurate at differentiating the grammatical versus ungrammatical test sentences ($p < .05$). Within the sleep condition, it was also found that the participants were more accurate on the novel category words ($p < .05$) while there was no difference in the wake condition ($p = .44$).

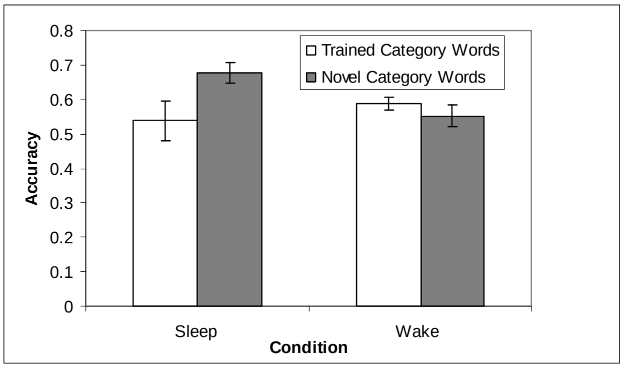

Figure 2: Accuracy in the 2AFC task by type of category word and sleep/wake condition.

To test whether the accuracy was significantly higher than expected by chance both wake and sleep conditions were tested against chance level. For the sleep condition, the participants were not significantly above chance with the trained category words, $t(4) = .66$, $p = .55$, but they were significantly more accurate than chance with the novel category words, $t(4) = 6.06$, $p < .01$. The exact opposite pattern was found in the wake condition, in that the participants were above chance for the trained category words but did not differ from chance on the novel category words, $t(4) = 5.13$, $p = .01$ and $t(4) = 1.63$, $p = .18$.

Discussion

When looking at the frequency manipulation in the trained category words, there was no evidence that sleep differentially influenced either the high or low frequency words which indicates that any difference found within the novel category words was not due to frequency differences. Previous research has shown that category word frequency has a large influence on categorization when distributional information is the only cue available to assist in this process. When phonological and distributional cues are combined high and low frequency words are readily categorized (St. Clair, 2007). However, it is interested to note that sleep-related learning also did not provide an additional high frequency advantage. However, the frequency manipulation in the study was minimal: high-frequency words occurred 64 times during training compared to 32 times for low-frequency words.

Additionally, the results indicated that learning the artificial language did not differ quantitatively when combined across the trained and novel category words for the sleep and wake conditions. However, there was a ***qualitative*** difference in what was learned from the sleep and wake conditions. With no sleep, participants show above chance discrimination of the test items with known category words, but no evidence of an ability to generalise beyond the known words to new category words with the same phonological characteristics. Strikingly, when the participants had a night's sleep between training and testing this generalisation ability emerged as the participants demonstrated an ability to generalise to the new category words, though the sleep group did not perform significantly differently from the wake group for the training items they heard the night before. Thus, it is in the ability to generalise beyond the known category words that the sleep and wake conditions differ, not in the categorisation of the training category words.

Our favoured explanation for the findings in the sleep condition is that sleep promotes the abstraction of the general characteristics of the category. These characteristics involve the phonological cues within the category words themselves. When faced with novel category words, the participants were able to use this more abstract conceptualization of the two categories to guide their decisions. However, this did not occur with the trained category words; this may have been due to the concurrent lexicalization process that occurs during sleep (Dumay & Gaskell, 2007). Indeed, it might be advantageous for the general phonological properties ***not*** to be applied to known category words, as this may interfere with processing the significant minority of nouns that sound like verbs, and verbs that sound like nouns. Further research will hopefully shed light on this issue.

An alternative explanation for the qualitative differences in learning between the sleep and wake groups was the quantity of stimulation that participants may have been exposed to between training and testing. The wake group were awake during this time, and this may have interfered with their learning. Another difference is that participants in the two groups were trained at different times of day, though circadian rhythm has not been shown to have an effect over effects of sleep in memory tasks, for instance (Gais, Werner, Wagner, & Born, 2000). However, the fact that performance on the trained category words was similar across the two groups, and even marginally better in the wake group, argues against this as the sole explanation for the abstraction effects we have observed.

Such demonstrations of generalisation over grammatical categories in artificial languages have been difficult to find in previous studies, and only seem to be observed in specific circumstances where the categories are supported by multiple, overlapping phonological, morphological, and distributional cues (Braine et al., 1990; Brooks, Braine, Catalano, Brody, & Sudhalter, 1993; St. Clair, 2007). The indication that sleep precipitates this generalisation process suggests that this may be a critical aspect of language development, particularly in terms of generalising abstract structure of the language (Gómez et al., 2006). This could mean that multiple cues are a necessity for learning grammatical categories, as claimed by Brooks et al. (1993), or it could be that this type of abstraction in learning requires consolidation during sleep.

Our study provides additional support that sleep is involved in the abstraction of phonologically consistent categories of words, and that sleep-facilitated generalisation can operate at a word category level, as well as a phoneme-category level (Fenn et al., 2003). This observation of generalisation coheres with other studies of the effects of sleep on non-language tasks (Fisher et al., 2006; Wagner et al., 2004), indicating that perhaps the same type of sleep-related neuronal change is the physiological basis of the difference between the sleep and wake conditions in each of these studies. The effect of sleep on learning is an instance of a general-purpose learning mechanism. We have demonstrated that coupling this mechanism with only some of the inherent richness of cues for producing grammatical categories from within language, is sufficient for generating abstract categories within language. Providing a cognitive description of the nature of this learning process associated with sleep, and exploring the potential for learning at all levels of language structure provides an intriguing possibility for future research in both normal and impaired development (Fabbro, Zucca, Molteni, & Renato, 2000).

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References

Black, A. W., Clark, R., Richmond, K., King, S., & Zen, H. (2004). Festival Speech Synthesizer (Version 1.95). Edinburgh: University of Edinburgh.

Bod, R. (2007). The data-oriented parsing approach: Theory and application. In J. Fulcher & L. Jain (Eds.), ***Handbook of computational intelligence***. Amsterdam: Springer.

Braine, M. D. S., Brody, R. E., Brooks, P. J., Sudhalter, V., Ross, J. A., Catalano, L., et al. (1990). Exploring Language

Acquisition in Children with a Miniature Artificial Language: Effects of Item and Pattern Frequency, Arbitrary Subclasses and Correction. ***Journal of Memory and Language, 29***, 591-610.

Brooks, P. J., Braine, M. D., Catalano, L., Brody, R. E., & Sudhalter, V. (1993). Acquisition of gender-like noun subclasses in an artificial language: The contribution of phonological markers to learning. ***Journal of Memory and Language, 32***, 76-95.

Cassidy, K. W., & Kelly, M. H. (1991). Phonological information for grammatical category assignments. ***Journal of Memory and Language, 30***, 348-369.

Cassidy, K. W., & Kelly, M. H. (2001). Children's use of phonology to infer grammatical class in vocabulary learning. ***Psychonomic Bulletin & Review, 8***, 519-523.

Chomsky, N. (1965). ***Aspects of the Theory of Syntax***. Cambridge, MA: MIT Press.

Chomsky, N. (2006). ***Language and Mind*** (3rd ed.). New York: Cambridge University Press.

Conway, C. M., & Christiansen, M. (2005). Modality-constrained statistical learning of tactile, visual, and auditory sequences. ***Journal of Experimental Psychology: Learning, Memory, & Cognition, 31***, 24-39.

Dumay, N., & Gaskell, M. G. (2007). Sleep-Associated Changes in the Mental Representation of Spoken Words. ***Psychological Science, 18***, 35-39.

Fabbro, F., Zucca, C., Molteni, M., & Renato, B. (2000). EEG abnormalities during slow sleep in children with developmental language disorders. ***Child Development & Disabilities, 26***, 41-48.

Fenn, K. M., Nusbaum, H. C., & Margoliash, D. (2003). Consolidation during sleep of perceptual learning of spoken language. ***Nature, 425***, 614-616.

Fischer, S., Drosopoulos, S., Tsen, J., & Born, J. (2006). Implicit Learning-Explicit Knowing: A Role for Sleep in Memory System Interaction. ***Journal of Cognitive Neuroscience, 18***, 311-319.

Fogel, S. M., Nader, R., Cote, K. A., & Smith, C. T. (2007). Sleep Spindles and Learning Potential. ***Behavioral Neuroscience, 121***, 1-10.

Gais, S., Mölle, M., Helms, K., & Born, J. (2002). Learning-dependent increases in sleep spindle density. ***Journal of Neuroscience, 22***, 6830-6834.

Gais, S., Werner, P., Wagner, U., & Born, J. (2000). Early sleep triggers memory for early visual discrimination skills. ***Nature Neuroscience, 3***, 1335-1339.

Gold, E. M. (1967). Language identification in the limit. ***Information and Control, 10***, 447-474.

Gómez, R. L., Bootzin, R. R., & Nadel, L. (2006). Naps Promote Abstraction in Language-Learning Infants. ***Psychological Science, 17***, 670-674.

McCabe, P. C., & Marshall, D. J. (2006). Measuring the social competence of preschool children with specific language impairment: Correspondence among informant ratings and behavioral observations. ***Topics in Early Childhood Special Education, 26***, 234-246.

Messer, S. C., Angold, A., Costello, E. J., Loeber, R., Van Kammen, W., & Stouthamer-Loeber, M. (1995). Development of a short questionnaire for use in epidemiological studies of depression in children: Factor composition and structure across development. ***International Journal of Methods in Psychiatric Research, 5***, 251-262.

Monaghan, P., Chater, N., & Christiansen, M. H. (2005). The differential role of phonological and distributional cues in grammatical categorisation. ***Cognition, 96***, 143-182.

Monaghan, P., Christiansen, M. H., & Chater, N. (2007). The Phonological Distributional Coherence Hypothesis: Cross-linguisitic evidence in language acquisition. ***Cognitive Psychology***(55), 259-305.

Pinker, S. (1991). Rules of language. ***Science, 253***, 530-535.

Reali, F., Christiansen, M., & Monaghan, P. (2003). Phonological and distributional cues in syntax acquisition: Scaling up the connectionist approach to multiple-cue intergration. In ***Proceedings of the 25th annual Conference of the Cognitive Science Society*** (pp. 970-975). Mahwah, NJ: Lawrence Erlbaum.

Reali, F., & Christiansen, M. H. (2005). Uncovering the richness of the stimulus: Structure dependence and indirect statistical evidence. ***Cognition, 96***, 143-182.

Redington, M., Chater, N., & Finch, S. (1998). Distributional information: A powerful cue for acquiring syntactic categories. ***Cognitive Science, 22***, 425-469.

Saffran, J. R. (2001). Words in a sea of sounds: The output of infant statistical learning. ***Cognition, 81***, 149-169.

Saffran, J. R. (2002). Constraints on statistical language learning. ***Journal of Memory and Language, 47***, 172-196.

Saffran, J. R., Aslin, R., & Newport, E. (1996). Statistical learning by 8-month-old infants. ***Science, 274***, 1926-1928.

St. Clair, M. C. (2007). ***Language structure and language acquisition: Grammatical categorization using phonological and distributional information.*** Unpublished Thesis, The University of York, York, UK.

St. Clair, M. C., & Monaghan, P. (2005). Categorizing grammar: Differential effects of succeeding and preceding contextual cues. In ***Proceedings from the 27th Annual Meeting of the Cognitive Science Society***. Mahwah, NJ: Lawrence Erlbaum Associates.

Valian, V., & Coulson, S. (1988). Anchor Points in Language Learning: The Role of Marker Frequency. ***Journal of Memory and Language, 27***, 71-86.

Wagner, U., Gais, S., Haider, H., Verleger, R., & Born, J. (2004). Sleep inspires insight. ***Nature, 427***, 352-355.

Walker, M. P. (2005). A refined model of sleep and the time course of memory formation. ***Behavioral and Brain Sciences, 28***, 51-104.