PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B

Phil. Trans. R. Soc. B (2009) **364**, 3607–3615
doi:10.1098/rstb.2009.0213

Introduction

Word learning and lexical development across the lifespan

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Word learning is one of the core components of language acquisition. In this article, we provide an overview of the theme issue on word learning, describing some of the ways in which research in the area has progressed and diverged. In recent years, word learning has become central in a wider range of research areas, and is important to research on adult, as well as child and infant language. We introduce 10 papers that cover the recent developments from a wide range of perspectives, focusing on developmental research, the influence of reading skills, neuroimaging and the relationship between word learning and general models of memory.

Keywords: word learning; acquisition; memory; psycholinguistics; neuroimaging; connectionism

1. INTRODUCTION

Word learning is a fundamental building block in the acquisition of language, and has often been identified as one of the 'special' components of language (e.g. Hauser *et al.* 2002; Pinker & Jackendoff 2005). Humans are phenomenally good at learning words, far exceeding the capabilities of other primates in this respect. By early adulthood, first language speakers will know at least 20 000 base words plus their morphologically complex forms, and some estimates suggest a far higher figure. Furthermore, word learning often appears swift and effortless, as exemplified by the fast-mapping phenomenon (Carey & Bartlett 1978) in which young children associate novel words and concepts within a small number of presentations. The unchallenged supremacy of young humans as word learners has to some extent encouraged researchers to study infant and child word learning in isolation, and to treat the mechanisms of word learning as distinct from other components of mental computation. But is it really the case that adults learn words in different ways when they encounter a second language, or a new word in their first language? And equally, is our remarkable capacity for learning words any different from our learning capacities for other entities such as visual scenes, where once again retention can be striking (e.g. Standing *et al.* 1970; Brady *et al.* 2008)? More importantly, what can we learn about children's vocabulary acquisition by looking at vocabulary acquisition in different ways, or by examining parallels with or divergences from other components of cognition?

In the last few years, research on word learning has advanced and diverged in several ways. Developmental research investigating children's learning remains at the core, but researchers in adult psycholinguistics have become more interested in vocabulary acquisition, from the point of view of first and second language learning, and as a means of refining models of word processing in its 'steady state'. Neuroimaging methods have matured, leading to new means of addressing the changes that take place in the brain as people learn new words. Finally, researchers have tried to address the relevance of models of general memory to the acquisition process. These divisions are undoubtedly beneficial, but come with a potential cost if researchers in different areas lose sight of the developments in their neighbouring fields. Our theme issue is intended to draw together a range of perspectives on word learning, in order to facilitate interactions between the many different approaches, to present a comprehensive review of the state of word-learning research and to begin to answer the questions posed above.

We introduce the papers that comprise the theme issue in four sections. We begin in §2 with three papers that cover the state of the art in developmental research, looking at infancy, lexical-semantic learning and bilingual acquisition. In §3 we describe two papers dealing with the influence of reading skills in word learning, both for children and adults. In §4 we review the two papers of the theme issue that focus on neuroimaging, and in §5 we introduce three papers relating word learning to more general models of memory.

2. WORD LEARNING IN INFANCY

Swingley (2009) presents an overview of research at the heart of word learning. His paper discusses the advances that have taken place in infant studies of word learning, with a particular focus on the first year or so of life. For this age group, methodology is crucial and in the last 20 years variants of the head-turn preference methodology (Fernald 1985) have

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proved invaluable. This technique allows two spoken stimuli differing in source location to be compared, with the experimenter measuring the preferred stimulus on the basis of head orientation (i.e. infants will orient their head towards the source of a more interesting stimulus for a longer period of time). It is generally accepted that the first 12 months of life involve a process of refining and tuning of the phonetic categories that are relevant to the infant's language. Contrasts that are unused in a particular language will tend to be lost, so that by 10–12 months of age only the phonetic categories that are relevant to a particular language remain. This important precursor to word learning has led to the assumption that vocabulary acquisition starts in earnest only in the second year.

Swingley's (2009) paper questions this assumption, arguing that there may be ways in which word learning can contribute more interactively to the refinement of phonetic categories. There is good evidence that infants, like adults, can make use of distributional information in the formation of phonetic categories (e.g. Maye *et al.* 2002). However, Swingley presents preliminary data suggesting that the distributions of real child-directed speech may be too noisy and overlapping to be of much use. One way in which the situation could be clarified is if a small number of learned words are used as prototypes for the phonemes that they contain. Thus, speculatively, distributional learning may facilitate early word learning, which in turn can help to refine categories.

Swingley (2009) also introduces a question that runs through many of the other papers in this theme issue. What does it mean to have learned a word? The most common answer is that both the word's form and its meaning must be accessible. However, Swingley reports a small set of developmental studies suggesting that these two components may be separable; that there may be an advantage in terms of learning the form first and the meaning second. Two different methodologies have found that familiarization with form alone can lead to better learning of meaning when a referent subsequently becomes available (Graf Estes *et al.* 2007; Swingley 2007). This is useful background to some of the later papers in the theme issue, which have focused specifically on the form rather than the meaning component of word learning (e.g. Davis & Gaskell 2009; Gupta & Tisdale 2009).

From around 12 months onwards, infants display knowledge of word meanings. Arias-Trejo & Plunkett (2009) review demonstrations of such effects, but argue that they tell us little as yet about the organization of semantic knowledge in the infant mind. In adults, detailed theories have been developed and tested, with the semantic or associative priming technique being an important tool in the process. This behavioural method involves the presentation of a prime word (e.g. cat) followed by a target word (e.g. dog), and the participant's response speed in different conditions of prime-target relatedness provides information about how semantic similarity is coded in the adult mind. Currently, information about word–word associations in the infant mind is lacking, although Arias-Trejo and Plunkett discuss event-related potential studies that provide preliminary evidence on this matter.

Demonstrating knowledge of word–word association in such a young age group is a challenging task, but Arias-Trejo & Plunkett (2009) attempt exactly that, with three experiments using a variant of the intermodal preferential looking task. Their basic paradigm involves spoken prime and target words (e.g. cat–dog), followed by the simultaneous presentation of two images, one of which depicts the target word. The extent to which there is preferential looking at the target image can then give a measure of the lexical activation of the target word. The experiments utilize several control conditions, perhaps the most critical being a condition where the prime is chosen to be an unrelated word (e.g. swing–dog). Using this methodology, Arias-Trejo and Plunkett find that 18-month-olds show no greater preference for the target picture in the related prime condition than the unrelated one. However, 21-month-olds do show selective facilitation when the prime word is related to the target. This constitutes the first clear evidence of semantic links within the infant lexicon, even though spoken word production at 21 months is often limited (and indeed the size of the priming effect was not correlated with vocabulary size).

Although the rather different picture for the 18-month-olds has to be interpreted carefully, one hypothesis discussed in the paper is that lexical concepts are initially represented as 'islands' in semantic space, with coherent and integrated semantic organization only emerging a little later in development. The data presented by Arias-Trejo & Plunkett (2009) represent an impressive proof of concept, but at this stage, they cannot discriminate between adult-like models of semantic memory. Nonetheless, the way forward is now clear for further tests of semantic priming in infants, examining in greater detail the ways in which semantic similarity is coded in the developing brain.

So far, we have discussed the challenges that are faced by infants growing up in a monolingual environment. However, in many cases, infants are confronted by two or even three languages from birth, depending on the native languages of their carers. How does word learning proceed when the language input contains this extra dimension of complexity? Werker *et al.* (2009) review the available evidence on this question. Their review encompasses many of the earliest stages of infant learning, including language discrimination, phonetic category formation, learning of phonotactic constraints, word learning and spoken word recognition.

One might expect that the increased demands of learning multiple languages at the same time would lead to substantial delays in reaching key stages in infant word learning. Perhaps surprisingly, the data available so far suggest that any differences between bilingual and monolingual infants are quite subtle, and that any delays for bilinguals are relatively short lived. For example, Fennell *et al.* (2007) examined the ability of young children to associate minimally different spoken sequences (e.g. 'bih' and 'dih') with visually presented objects. This kind of mapping can be performed by monolingual infants by 17 months, although the difficulty of the minimal distinction means that 14-month-olds fail. Fennell *et al.* found that bilingual infants failed this task at both 14 months and 17 months, but nonetheless 20-month-olds were able to learn the mappings. Werker *et al.* (2009) argue that much of the monolingual data in this area can be explained in terms of computational resource limitations: monolingual infants at 14 months can learn new words, but only when task demands are less severe, whereas 17-month-olds have a greater capacity to learn in more demanding circumstances. By extension, the extra level of complexity in the bilingual case may mean that even 17-month-olds fail at the minimal pair association task.

Intriguingly, Werker *et al.* discuss a small number of cases in which learning abilities appear to be superior for bilinguals (Kovács & Mehler 2009; Mattock *et al.* in press). In these cases, it may be that the extra demands placed on bilingual learners have the side-effect of instilling a greater flexibility in general cognitive processes, an advantage that may remain even in adulthood (Costa *et al.* 2008).

3. WRITTEN WORD LEARNING IN CHILDREN AND ADULTS

Children start to learn to read some years after they begin to talk. Where we might reasonably propose genetic support for spoken language acquisition, the fact that writing is a recent invention, and that only a tiny minority of the people who have lived and died on this planet have ever learned to read, means that the acquisition of literacy, including the acquisition of new written words, must be supported by other, more general cognitive and neural systems.

As Nation (2009) observes, much of the empirical research on how children learn to read has been concerned with the ability to read words and sentences aloud correctly. It is easy to understand that focus: it is straightforward for researchers to measure the accuracy with which children can read words or sentences aloud, but much more difficult to assess whether they understand those words and sentences fully, partially or not at all. Yet, the purpose of reading is understanding. Pleasure and enlightenment are derived from comprehending the meaning of text rather than converting it from print to sound.

After providing an overview of how children learn to map print to sound, Nation (2009) turns to a consideration of how they learn to associate written words with their meanings. Sound plays an important role here: if a child can pronounce a written word correctly, they have a chance of accessing its meaning from its sound, even if they have never seen the word in print before. That is easier for some words than others. A basic knowledge of the letter–sound correspondences of English will allow a child to read regular words like *cave, hint* or *boat* correctly, but irregular words like *have, pint* or *yacht* defy the normal rules of English. Nation reviews evidence suggesting that knowledge of word meanings (semantics) plays a part in accessing the correct pronunciation of irregular words, especially relatively low-frequency ones that are not being constantly encountered in print. Recent support for this claim comes from a word-learning study by McKay *et al.* (2008), who taught adults to read a set of fictitious words aloud. Some of the new words obeyed the regular letter–sound correspondences of English while others had irregular (exceptional) pronunciations. Furthermore, some were taught with meanings and others without. Having a meaning to associate with a new word facilitated reading that word aloud, but only if it had an irregular pronunciation. Gathering evidence using real words to support the claim that meaning contributes to reading aloud irregular exception words but not regular words with consistent pronunciations is fraught with difficulty because of the near impossibility of matching different sets of real words on frequency, imageability, length, age of acquisition and all the other factors thought to influence reading speed (Monaghan & Ellis 2002; Strain *et al.* 2002). Addressing the same issues in a word-learning study using fictitious words affords much greater control over the stimulus characteristics and generates results that are more likely to find general acceptance.

Nation & Cocksey (2009) carried out a study of children's reading that was similar in principle to the word-learning study of McKay *et al.* (2008). They assessed the ability of 7-year-old children to read words with regular or irregular spelling sound correspondences. At the same time, they assessed children's understanding of what those words meant. The correlation between understanding what a word means and being able to read it aloud correctly was higher for irregular than for regular words. But experiments of this sort deal with the ability to read words presented in isolation, out of context. Nation (2009) notes that the context in which a word appears can also provide clues as to its identity, and therefore its pronunciation. Even if a young child has never seen the written word *hill* before, it is likely to be read correctly if it comes at the end of the sentence *Jack and Jill went up the hill*. Nation observes that young readers, and older readers who are not skilled at letter–sound conversion, rely more on context when reading words aloud than do older and more skilled readers.

Understanding written text requires more than just understanding the meanings of the component words. The structure of sentences must be processed in order to derive the meaning of the sentence as a whole, and the meanings of successive sentences must be combined in order to grasp the meaning of whole paragraphs or even stories. Research on children's reading has shown that children who are reasonably good at reading individual words, but bad at understanding written text ('poor comprehenders') show the same problems in understanding spoken language (Nation 2005). The implication of this is that the cognitive processes that assemble the meanings of phrases, sentences and texts operate on both spoken and written language. What is unique about learning to read is the remarkable way that readers learn to recognize letters across different shapes and forms (e.g. f, *f*, F, *F*) and to recognize words that are differentiated only by the number and sequence of their component letters. Ellis *et al.* (2009) investigated the role of the two cerebral hemispheres in learning and processing new written words. In two experiments, right-handed adults learned to recognize and read aloud fictional new words of varying length (four or six letters). Training involved a mixture of reading the new words aloud, copying them in the participants' own handwriting and reading them in sentences that provided hints as to their possible meanings (e.g. *The comy only eats fish*; *He picked the menfal off the shelf*). Participants were tested on the speed and accuracy of reading aloud the new words (interleaved with real words) both before and after training.

To assess the contributions of the two hemispheres of the brain to word learning and lexical processing, the familiar words and new words were displayed briefly either to the left or to the right of a central fixation point for the naming tests. The anatomy of the human visual system dictates that words displayed to the right of fixation project directly to the left cerebral hemisphere, which, for most right-handed people, is the language-dominant hemisphere. Words displayed to the left of the fixation point project initially to the right cerebral hemisphere. If, as is commonly proposed, word recognition occurs within the left hemisphere, then words from the left visual field (LVF), which arrive first in the right hemisphere, must be transferred to the left hemisphere across the corpus callosum if they are to be identified, pronounced and understood. That requirement for interhemispheric transfer may be partly responsible for the well-attested fact that words (and non-words) viewed in the right visual field (RVF) are recognized more quickly and more accurately by right-handed people than words viewed in the LVF—the so-called RVF advantage (Ellis 2004; Hunter & Brysbaert 2008).

Many studies of lateralized word recognition have shown that the number of letters in a familiar word has more of an impact on the speed and accuracy of recognition when presented in the LVF than the RVF. This has led to the suggestion that LVF/right hemisphere word recognition is inherently more serial in character than RVF/left hemisphere recognition (Ellis 2004). Ellis *et al.* (2009) show how recognition in the two visual fields changes as letter strings pass from being unfamiliar non-words to being newly learned words. Before any learning has occurred, unfamiliar non-words that are presented very briefly are read aloud with long latencies and many errors. Naming is more accurate and faster from the RVF than from the LVF, but performance in both visual fields is worse for non-words than for familiar words. This is particularly true for longer non-words: increased letter length results in more errors and slower naming in both visual fields when the non-words are as yet unfamiliar. After learning, the pattern of results changes dramatically. Naming of learned non-words becomes faster and more accurate in both visual fields: indeed naming times for newly learned non-words are as fast as naming times for familiar words. The pattern of length effects also changes radically. Before training, two more letters in an unfamiliar non-word increases naming times by around 80 ms in both visual fields, indicative of highly serial processing of unfamiliar non-words, wherever they occur in visual space. After training, two more letters in a learned non-word increases naming times by 50 ms in the LVF but only 8 ms in the RVF. Learned non-words that appear in the LVF, and therefore project initially to the right hemisphere, retain signs of serial processing (though less than for unfamiliar non-words). In contrast, the processing of learned non-words that appear in the RVF, and therefore project initially to the left hemisphere, is more parallelized, with additional letters making little difference to naming speeds. This matches the pattern generally observed for familiar words (Ellis 2004).

The explanation of these findings proposed by Ellis *et al.* (2009) is based on the establishment of orthographic, semantic and phonological representations for newly learned words, especially the establishment of orthographic representations in the so-called 'visual word-form area' in the left mid-fusiform gyrus (McCandliss *et al.* 2003). Creating a representation for a newly learned word that encompasses the complete letter sequence that forms the word will allow that word to access its pronunciation on a holistic basis. Unfamiliar non-words, in contrast, lack whole-string representations and must be pronounced in a piecemeal, analytic fashion using sublexical letter–sound correspondences. The number of elements in a letter string would be expected to affect sublexical procedures applied to naming unfamiliar non-words more than lexical procedures applied to familiar words or newly learned non-words. That transition from sublexical to lexical orthography-to-phonology conversion shortens naming speed and improves accuracy while reducing length effects for both RVF and LVF words. It cannot explain, however, why length effects remain greater for LVF than RVF words or learned non-words. Ellis *et al.* (2009) propose that those hemifield- and hemisphere-specific differences arise as a result of interactions between word forms in the left mid-fusiform gyrus and earlier systems responsible for identifying the component letters of words and non-words—systems that are thought to reside in lateral occipital cortex in the region of the middle and inferior occipital gyri. The proposal is that the presentation of a familiar word in the RVF triggers an interaction between left lateral occipital and mid-fusiform areas that is akin to the 'interactive activation' between earlier and later processing levels that is incorporated in some cognitive models of word recognition (e.g. the DRC model of Coltheart *et al.* (2001)). The consequence of that interaction, it is suggested, is faster resolution of the component letters of RVF words and a lower cost of additional letters. LVF words arrive first in the right hemisphere and must be transferred across to the left hemisphere. Their delayed arrival, and possibly weaker activation of left hemisphere systems, may induce less interaction between lateral occipital and mid-fusiform regions, and therefore less of an amelioration of the effect of letter length. Ellis *et al.* (2009) end with a consideration of how these ideas and observations may apply to words viewed centrally, at fixation.

4. INSIGHTS INTO WORD LEARNING FROM BRAIN IMAGING

As discussed above, infants are born with the ability to discriminate a wide range of different sounds, but then may lose the capacity to differentiate between sounds that are not distinguished in their own language, even though they may be distinguished in other languages. Dobel *et al.* (2009) give the example of /t/-/d/ discrimination, which is found in English but not Korean with the result that native speakers of Korean who are approaching English for the first time find it very difficult to hear the difference between words like 'dip' and 'tip'. The perceptual system is tuned by experience to group different exemplars of the same phoneme into a single acoustic category. If it transpires that another language makes a distinction where the native language does not, it can be very difficult for an adult to retune their perceptual system to register that distinction.

Dobel *et al.* (2009) attempted to teach adult speakers of German to distinguish /f/, a common phoneme in both English and German, from a phoneme that is transcribed as /Φ/ in the International Phonetic Alphabet and that occurs in several African languages. The sound of /Φ/ is described as being 'reminiscent of a soft blow of air through open lips'. Dobel *et al.* created pairs of novel words that were identical except that a consonant in an initial, medial or word-final position was /f/ in one of the new words and /Φ/ in the other. Training over 5 days involved pairing the new words with pictures of familiar objects (e.g. pairing /afa/ mostly with pictures of buses, and /aΦa/ mostly with pictures of glasses). At a behavioural level, learning was assessed using a multiple-choice task. On each trial of the multiple-choice task, participants heard one of the novel words and saw four pictures. One picture had been frequently presented with the novel word (e.g. a picture of a bus for /afa/), one picture had been frequently presented with the word that differed only on the /f/ versus /Φ/ distinction (which in this example would be a picture of a glass) plus two pictures that had not been associated with either the target word or its close neighbour. Performance on this task rose over the course of training to over 80 per cent correct at the end of day 5, although even at the end of training participants often confused /f/ and /Φ/.

Participants were also given a version of the word–picture matching task in a magnetoencephalography (MEG) scanner before and after training. On each MEG trial, one of the newly learned spoken words was presented, followed by a picture that either matched the spoken word or was a mismatch. Analysis focused on the period from 350 to 500 ms after picture presentation during which a neural response called the N400m occurs. This response is known to be sensitive to mismatches between what is expected and what actually happens. The question at issue was whether, for example, the novel word /aΦa/ followed by a picture of a glass (the correct picture) would generate a different N400m response from the same non-word followed by a picture of a bus (a mismatch which should be paired with /afa/, not /aΦa/). The N400m response showed the expected sensitivity to novel words created using entirely German phonemes. There was also a reduction over the course of training in the N400m response to novel words containing the /Φ/ sound, implying that the auditory system had gained some familiarity with that sound. But the N400m response, like the behavioural multiple-choice task, failed to distinguish between novel words containing /f/ and novel words containing /Φ/. The /Φ/ sound had been learned to some extent, but it was classified both behaviourally and neurally as a variant of /f/ rather than as a separate phoneme that distinguishes a set of words containing /Φ/ from a set containing /f/. The results confirm how hard it is for the mature mind and brain to learn to hear and differentiate new phonemes that do not form part of the native language inventory. Dobel *et al.* end with some speculations about modified training regimes that they hope might prove more successful.

Rodríguez-Fornells *et al.* (2009) provide a comprehensive and wide-ranging review of the acquisition of spoken language by children and adults. They note that while young children are often regarded as more natural language learners than adults, studies of adult second language learners have reported that a proportion at least achieve native or near-native levels of performance, even in notoriously difficult areas like the acquisition of syntax and phonology. Depending on the criteria used, and possibly the population studied, the proportion that acquires near-native fluency varies from around 5 per cent to over 20 per cent. Differences between adult and child language learners may not be as dramatic or as fundamental as has often been assumed.

Rodríguez-Fornells *et al.* (2009) revisit and update arguments that have been running within psychology and linguistics for 50 years or more, such as whether children come into the world equipped with a dedicated language learning device or acquire language through the application of more general learning mechanisms. Their review pays particular attention to two issues—how language learners isolate words and grammatical rules from continuous speech samples, and how they map new words onto existing meanings acquired through either non-verbal experience or learning an earlier language. Rodríguez-Fornells *et al.* discuss three 'interfaces' that they regard as particularly important for language acquisition. The first is the interface between auditory and pre-motor processes that allows language learners to attempt to pronounce words and phonemes that they may be encountering for the first time. Crucial to this interface is the linking of regions in the posterior left temporal lobe that are involved in speech perception with frontal areas that sustain speech motor programming. The second of Rodríguez-Fornells *et al.*'s vital interfaces is the 'meaning integration interface', which evaluates the meanings of new words on the basis of both verbal and non-verbal clues. This function is thought to be mediated by the so-called 'ventral language stream', which links medial, inferior and anterior regions of the left temporal lobe concerned with representing meaning to areas in ventral inferior motor cortex involved with planning and selection of responses. The third and final interface is that between episodic memory for individual events or experiences and lexical memory, which consolidates those experiences into new lexical representations linked to meanings. The important neural structures here appear to be the hippocampus and those cortical areas within the medial temporal lobes with which it is closely associated (parahippocampal, entorhinal and perirhinal cortex). Rodríguez-Fornells *et al.* end by noting that the time is rapidly approaching when cognitive neuroscience must move beyond the necessary first step of delineating the structures involved in the various language-related neural networks to analysing the dynamic flow of information within and between them. Techniques such as electroencephalography (EEG) and MEG, which allow neural events to be analysed with millisecond accuracy, will play an important part in this next step.

5. INTEGRATING WORD LEARNING WITH MODELS OF MEMORY

The final papers of the theme issue attempt to relate word-learning processes to more general models of memory. Although word learning can sometimes be thought of as a specialized or modular component of cognition (Hauser *et al.* 2002; Pinker & Jackendoff 2005), there are clear parallels between memory for words and other forms of memory, and perhaps these parallels have not yet been sufficiently exploited. Page & Norris (2009) review data on one of the strongest links: between vocabulary acquisition and measures of working memory. For example, Gathercole & Baddeley (1989) showed that a child's ability to repeat non-words varying in complexity was a strong correlate of their vocabulary size, suggesting a causal role for working memory in the acquisition of words. Page & Norris (1998) have previously published a model of working memory, focusing on the immediate serial recall task, but in their current paper they examine how this might be extended to word learning, and even to the process of spoken word recognition. Page and Norris argue that a crucial piece of evidence linking working memory and word learning is the Hebb repetition effect (Hebb 1961). This paradigm involves repeated presentation of stimuli (e.g. letters), for immediate serial recall, with certain lists repeated several times at regular intervals. Although participants typically do not notice this repetition, their performance on recall of the repeated lists improves on each repetition. The clear implication is that each episode of presentation involves learning, and Page and Norris argue that this learning is no different from the learning that goes on when a new word is acquired. They support this argument by showing that the Hebb repetition has several key properties that would be expected if the same learning mechanism really does underlie both phenomena. Like word learning, Hebb repetition effects are fast, long-lasting and can be found in both adults and children.

Given these similarities, Page & Norris (2009) present a model that is intended to cover aspects of both working memory (immediate serial recall and Hebb repetition) and vocabulary processing (word-form learning and recognition). The model is based on connectionist principles and involves several layers of localist nodes representing the occurrence of basic speech units (e.g. phonemes), as well as sequences of units and their order. The authors show that this kind of model can accommodate the Hebb effect by recruiting new units to represent 'chunks' or sequences of phonemes. It follows that this simple chunking mechanism can likewise be used to learn novel words in exactly the same way.

The paper concludes by relating the authors' model to others that incorporate a learning component alongside short-term memory. Although the Page and Norris model is as yet better developed in terms of its memory side than its language side, it provides some clear proposals for how it may be extended. Many researchers in language acquisition might find the Hebb effect a somewhat artificial task, and a far cry from the learning situation faced by a 2-year-old child learning to associate an isolated new word and its referent. Nonetheless, some language acquisition studies have employed more comparable learning situations (e.g. Saffran *et al.* 1996; Estes *et al.* 2007), suggesting that the attempt to find a unifying mechanism underlying working memory and word learning is a valuable one.

At a broad level, Gupta & Tisdale's (2009) overall aim is rather similar to that of Page and Norris: they wish to develop a modelling framework that encompasses both phonological short-term memory processing and language learning. However, both the detailed issues addressed in their paper and the architecture of the resultant modelling framework are rather different. Gupta and Tisdale begin by reviewing some of the factors that determine the ease with which novel words can be processed in the short term, and stored in the long term. These include phonological short-term memory, vocabulary size, phonotactic and neighbourhood factors, as well as long-term knowledge. In discussing the impact of long-term knowledge, the authors highlight the distinction between systematic and arbitrary mappings. In terms of language function, the mapping from a heard phonological form to a representation of spoken output (as in immediate serial recall or repetition) can be characterized as relatively systematic, whereas the mapping from form to meaning (as in recognition) is near arbitrary. This turns out to be an important distinction because Gupta and Tisdale utilize a distributed connectionist modelling framework, for which fast learning of new mappings can occur only in the case of systematic mappings. Thus, by focusing on tasks involving the phonological form of novel words, Gupta and Tisdale argue that one can capture at least some aspects of both phonological short-term memory and word learning within a single distributed network model.

The model that Gupta and Tisdale describe (Gupta & Tisdale in press) is based on a connectionist model of short-term memory (Botvinick & Plaut 2006), but focuses on the extent to which this model can be extended to explain the process of word learning. Many of the properties that the research uncovers stem from this intimate link between short-term memory and vocabulary. For example, non-word repetition (a measure of short-term memory functionality) improves as the vocabulary size of the model increases. Likewise, Gupta & Tisdale (2009) present new data showing that high phonotactic probability sequences (i.e. containing more common phonemes) lead to more accurate performance in the course of word learning than sequences with a low phonotactic probability (cf. Storkel & Rogers 2000).

Gupta and Tisdale clearly demonstrate the feasibility of accommodating short-term memory and vocabulary acquisition phenomena within a single distributed connectionist system. As the authors discuss, the framework they advocate is currently limited, but like Page & Norris (2009), the parsimony of a model encompassing several major areas of cognitive psychology is attractive. The next challenge in this case may be to address the interactions between the established form mappings and access to meaning.

The final paper in this section relates quite strongly to Gupta and Tisdale's work. Davis & Gaskell (2009) also discuss the problem of learning arbitrary mappings in distributed connectionist systems, and describe one solution to this problem, the complementary learning systems model (McClelland *et al.* 1995). This model has been applied to many aspects of memory, and assumes that alongside a distributed (neocortical) route, there is also a sparser (hippocampal) route specialized for fast learning of new mappings. Davis and Gaskell discuss a set of studies that examine to what extent this general model of memory can be applied to vocabulary acquisition. One clear prediction of a complementary systems account is that there will be immediate effects of learning (based on the hippocampal route), but also more extended offline transfer of knowledge between the two systems. Thus, learning new words should have some observable delayed effects, depending on the way in which memory has been probed.

The authors review several studies that show such effects, using both spoken and written word learning (e.g. Gaskell & Dumay 2003; Bowers *et al.* 2005). Key to the observation of delayed effects of learning is whether the integration of novel words with their existing neighbours is assessed. The data suggest that novel words are learned in an encapsulated form initially and only later integrated fully with their neighbours (with the slower integration process being associated with sleep; Dumay & Gaskell 2007). Davis & Gaskell (2009) go on to discuss neuropsychological and neuroimaging data relating to a dual systems account of word learning. On the neuropsychology side, a complementary systems account predicts that damage to the hippocampus would lead to word-learning problems, whereas damage to neocortical areas would lead to processing problems for known words. The paper evaluates both these predictions, with word-learning studies in amnesics supporting the hippocampal role in learning, and a range of aphasic conditions supporting the neocortical role.

The data from neuroimaging are not as comprehensive, but there are now several studies implicating the hippocampus in the learning of new words. In order to clarify the predictions of their account on the neocortical side, Davis & Gaskell (2009) carry out a meta-analysis of positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) studies that compares responses to words and pseudowords. This reveals a network of areas that respond differently to words and pseudowords, and thus represents the neocortical 'signature' of a known word. In particular, two portions of the left superior temporal gyrus show a stronger response to pseudowords than words, perhaps relating to dorsal and ventral pathways in the processing of spoken stimuli. With this lexical signature established, Davis and Gaskell describe a recent study that attempted to look for immediate and delayed neural correlates of word learning (Davis *et al.* 2009). As with previous research, this study found immediate effects of learning in the hippocampus, but importantly, the neocortical areas implicated in lexical processing by the meta-analysis were not affected. These areas only showed word-like responses to novel words for a set of items that had been learned one day prior to the fMRI session, consistent with a role for offline consolidation in neocortical learning.

The combined behavioural, neuropsychological and neuroimaging data provide a reasonably supportive case for the application of a general dual systems model of memory to the specific case of word learning. Once again though, there are some important caveats to the approach with very little of the current work in this area being concerned with the acquisition of word meanings (Leach & Samuel 2007). Returning to the first paper of the theme issue (Swingley 2009), there is reassuring evidence from development that form learning is a useful component of the vocabulary acquisition process, but nonetheless there remain some rather substantial gaps to be filled in all the models described so far before we can have a full view of how word learning fits in with our general systems for cognitive processing.

We are very grateful to the UK Experimental Psychology Society and the Department of Psychology at the University of York for funding the workshop from which this theme issue developed, and to the participants in that workshop for the many valuable discussions that ensued. We also thank the following people, alongside the theme issue authors, for providing reviews and comments: Marc Brysbaert, Neil Burgess, Robert Davies, Nicolas Dumay, Simon Farrell, Anne Fernald, Tom Hartley, Jessica Horst, Michal Lavidor, Marcus Meizner, Rebecca Millman, Miguel Peréz, Gorana Pobric, Michael Simpson, Leher Singh, Marilyn Vihman and Dan Weiss. M.G.G. was supported by a fellowship awarded by the UK Economic and Social Research Council (RES-063-27-0061).

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