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**Abstract**

There has been little research exploring whether different memory processes (i.e. related to short term memory (STM), working memory (WM) and long term memory (LTM) may be differentially sensitive to representation and processing aspects of compound words. This study investigated how compound words are represented in STM in immediate serial recall tasks and in WM in complex span tasks that combine processing and storage demands. The simple span STM task was comprised of solely a list of memory words, whereas the two complex span WM tasks interleaved sentence processing between presentation of memory words. They varied in the presence of a pause after presentation of each memory word and before onset of the following distractor sentence for processing. The absence of a pause was intended to minimize opportunity for subvocal rehearsal, whereas the presence of a pause encouraged rehearsal. To increase chances of recombination errors for error analyses, lists of memoranda were manipulated so that each set (list) of four compound words contained one “lure” pair (e.g. *pinstripe* + *warhead* = *pinhead*) in which the modifier and head constituents from separate compound words could recombine to form a new, legal word.  Recall performance was better in the simple span and complex span pause tasks compared to the complex span no pause task. Whole compound and left constituent frequencies played opposite roles, helping and harming, respectively. Error types reflecting decomposition of the compound words to their constituents were more common in simple span than in complex span. Omissions were more common in complex span. We discuss how different

memory processes may be differentially sensitive to representation and processing aspects, and how recall of compound words is affected by various lexical variables.

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I would like to dedicate this thesis to my parents, who have supported me throughout my time in academia. They are both an inspiration to me and I am forever grateful for what they have allowed me to accomplish in my life.

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## Introduction

From the onset of language acquisition, humans are endowed with the ability to process, store and retrieve words of varying morphological complexity that are represented in their mental lexicon (Fiorentino & Poeppel, 2007). Although words can vary greatly in how morphologically complex they are, the most basic unit remains the same: the morpheme. Morphemes are the smallest linguistic units that carry meaning and are referred to as the "building blocks of our mental lexicon" (Juhasz, 2012). These "building blocks" are the most basic components of morphologically complex words, including compound words. In the current study, the processing of compound words in working memory (WM) tasks was examined. Compound words form a category of interest as they consist of two or more semantically independent constituents, or lexemes, that can be assumed to have separate representations in the mental lexicon but also combine to form new meanings (Eiesland & Lind, 2012). Thus, compound words offer researchers the opportunity to explore how storage and composition tasks are implemented in the mind (Badecker, 2007; Fiorentino & Poeppel, 2007). The present study explored whether task type and various lexical variables, such as semantic transparency, frequency, entropy of the relational distribution of the compound word, and the morphological family sizes of the left and right constituents affect the kinds of recall errors made, specifically, recombination errors (new words consisting of two constituents from two different words). As such, the present study used "lure pairs" to encourage recombination errors. These pairs of compound words contained constituents that could be recombined to form new, legal words. Recombination errors may provide insight into how compound words are represented in the mental lexicon and how they are decomposed during various tasks that tax memory processes.

**Early research in morphological processing**

A current topic of debate that has been addressed over the past decades in psycholinguistic literature is how morphologically complex words are processed and represented in the mental lexicon. More specifically, research (Boutonnet, McClain, & Thierry, 2014; Fiorentino & Poeppel, 2007; Juhasz, 2008; MacGregor & Shtyrov, 2013; Marelli & Luzzatti, 2012; Semenza & Luzzatti, 2014; Zwitserlood, 1994) has aimed to determine whether morphologically complex words are processed as wholes or via their morphological constituents. Research (Badecker, 2007) has examined the mechanisms that assemble morphologically complex words and whether these words necessitate parsing the complex word form into its constituent morphemes in reading, listening, naming, lexical decision and other psycholinguistic tasks. Early research in morphological processing saw the formation of three major classes of theory of morphological processing. The Full Listing Hypothesis (Butterworth, 1983) maintains that all word forms, including derived and inflected forms, are listed in the mental lexicon and, thus, have their own lexical representation. This method of lexical organisation would require the mental lexicon to have a large capacity for all word forms, as decomposition does not take place (Libben, 1998). An alternative are full-parsing models

(Taft & Forster, 1976), which propose that morphologically complex words undergo automatic parsing with independent access to their constituent morphemes. According to this approach, multimorphemic words' lexical representations are stored in stem form. The stem form acts as a target for the lexical search and allows incoming stimulus letter strings to be matched to it. This, in turn, makes information about the complete word available. In other words, morphological constituents are needed in order to access the whole word form (Taft & Forster, 1976; Taft, 1988). Alternative views (e.g. Giraudo & Grainger, 2001) claim that whole word form activation occurs prior to the activation of the morphological constituents. The process and representation of multimorphemic words is dependent upon the language studied as well as a multitude of lexical factors such as frequency, morphological type (inflected, derived, compounded), lexical category (verb, noun, etc.) and the semantic relationship between the multimorphemic constituents (Libben, 1998). Lexical decision tasks (Sandra, 1990) using semantic primes have found that semantic transparency plays a role in how a multimorphemic word is decomposed during recognition, with transparent compounds (e.g. beanpole, teaspoon) being processed through morphological decomposition. No priming effects were found for semantically opaque compounds (e.g. buttercup). In addition, neither of these models offers a full explanation of experimental data. Dual route models of processing (Pollatsek, Hyönä, & Bertram 2000; Schreuder & Baayen, 1995) have surfaced to explain the full set of findings by proposing that lexical access for morphologically complex words is achieved by both a whole-word and a parsing procedure. Such alternative theories

(Badecker, 1991; Laudanna, Badecker & Caramazza, 1992) are categorised as hybrid theories, as they assume use of both full forms and decomposition.

Badecker (1991) conducted a case study with a patient with acquired lexical impairment and found that reading performance was affected by the morphological complexity of stimuli; monomorphemic words such as *lynx* and *freeze* were more easily read than corresponding suffixed homophones such as *links* and *frees*. Although such findings appear to indicate the presence of morphological decomposition procedures, the author suggests that a whole word entry for a suffixed word may simply be more complex representationally. Alternatively, multimorphemic words may be more difficult to activate than monomorphemic words (Badecker, 1991). Lexical decision tasks (Laudanna et al., 1992) have also been used to explore the nature of decomposition for morphologically complex words, such as inflected and derived words, in the mental lexicon. Results showed the existence of a level of lexical representation in the input lexicon for derived and inflected words. Here, derived and inflected words were thought to be analysed by their inflectional stems and affixes, but not in terms of their derivational affixes and roots. Different patterns of effects for these two classes of words suggest that morphological structure is represented at various levels in the mental lexicon (Laudanna et al., 1992).

**Current research in morphological processing**

Currently, the majority of findings examining decomposition of morphologically complex words (Eiesland & Lind, 2012) appear to support the idea that such words are, in addition to being accessed via their whole forms, also accessed via their constituents. In the past 30 years, answers as to how morphologically complex words are processed and represented in the mental lexicon have largely been sought by examining inflections and derivationally complex words but, to a lesser extent, compounds (e.g. Fiorentino & Poeppel, 2007; Semenza & Luzzatti, 2014; Service & Maury, 2015). For the past few decades, the role of morphological and semantic complexity in compounds has also attracted attention, as these words possess both lexical and semantic characteristics and are, therefore, of particular interest in language processing (Eiesland & Lind, 2012; Semenza & Luzzatti, 2014). In addition, studies using compound production (Fiorentino & Poeppel, 2007; Semenza, Luzzatti, & Carabelli, 1997) and comprehension (Hirose & Mazuka, 2015) have provided valuable insight into the storage and composition of linguistic terms in the mental lexicon.

It remains unclear what the underlying mechanisms in dual-route processing of morphologically complex words are. The most recent versions of a well-known dual-route model suggest lexical processing is a cooperative and flexible maneuver that requires information from both the individual compound constituents and the compound word as a whole (Kuperman, Schreuder, Bertram, & Baayen, 2009; Semenza & Luzzatti, 2014). A number of studies (Fiorentino & Poeppel, 2007; Semenza, Luzzatti, & Carabelli, 1997) have found support for compositionality, which contends that the individual constituents of a compound word are stored and accessed separately and are only combined during production. In comprehension, the compound word is decomposed into its individual constituents. In contrast, non-compositional models (Bybee, 1995) suggest complete storage of all morphological items, regardless of how morphologically complex they may be.

An additional aspect regarding the processing and production of compound words is proposed by the "lemma" model (Levelt & Meyer, 1999), which postulates the existence of an intermediate level (the lemma) between phonological and semantic information. This binds a word's semantic and grammatical features. Each of the existing lexical concepts of a language is defined as a lemma: a canonical form of a word containing grammatical properties. By the age of 4, humans have acquired a functioning system of lemmas from which the appropriate lemma must be selected during speech production (Levelt & Meyer, 1999). Beyond the lemma exists the lexeme, which is used to store the phonologically specified word form. However, information regarding the compound status of a word can only be explained by storage at the lemma level, as this is where the word's grammatical properties are specified (Semenza & Luzzatti, 2014).

**Semantic transparency**

The above-mentioned models focus on the lexical aspects of word processing and do not broach the effect of semantic properties of processing of morphologically complex words (Semenza & Luzzatti, 2014). To date, there is a growing amount of evidence suggesting that the notion of semantic transparency is key to understanding how multimorphemic words are represented in the mind (Libben, Gibson, Yoon & Sandra, 2003). Traditional models propose that semantics imposes an effect in late stages of word processing (Libben, 1998). However, more recent proposals suggest that the semantics of compound words modulates lexical access already during earlier stages of word processing (Marelli & Luzatti, 2012). Zwitserlood (1994) examined the processing and representation of Dutch compounds as a function of semantic transparency using repetition and semantic priming tasks. Results indicated that regardless of semantic transparency, there appeared to be constituent priming by compound words: priming of semantic relatives of the target constituents resulted in significant priming effects only for the totally and partially transparent constituents (e.g. *kerkorgel* (church organ) and *drankorgel* (drunkard), both with same second constituent *orgel*, meaning "organ"). It was concluded that the constituent morphemes of completely opaque compounds do not exhibit a connection with one another at a level of semantic representation (Zwitserlood, 1994). A similar study (Libben et al., 2003) examined the role of semantic transparency in both the representation and processing of English compounds. More specifically, the question of whether semantic transparency of the compound is processed for an entire multimorphemic string or, rather, separately for the constituent morphemes, was addressed. Contrasting semantically transparent and opaque compound words showed that both could be parsed into constituents affecting task performance. Furthermore, the semantic transparency of the morphological head was found to play a crucial role in terms of lexical decision latencies, stimulus repetition effects and patterns of decomposition, suggesting an emphasized role for the head in semantic processing (Libben et al., 2003). These researchers also aimed to determine whether semantic transparency should be viewed as a characteristic of the entire multimorphemic string or of the separate constituent morphemes. Recent studies have described multimorphemic words in terms of their transparency by determining whether the constituent morphemes are transparent in meaning or opaque. In regards to the semantics of the individual constituents of a compound, three kinds of compound words have been identified: 1) Those consisting of two semantically transparent constituents, such as *bedroom*, 2) those consisting of one semantically transparent constituent and one semantically opaque constituent, such as *strawberry*, and 3) those consisting of two semantically opaque constituents, such as *hogwash* (Zwitserlood, 1994). Compound words containing semantically opaque constituents in head position are less common than those containing them in modifier position (Libben, 2014). Libben (2014) provides English compound word examples such as *jailbird*, whose first constituent is semantically transparent and whose final constituent is semantically opaque, as being less common than compound words such as *nickname*, whose first constituent is semantically opaque and whose final constituent is semantically transparent.

**Headedness**

*Headedness*, referring to the internal order of and relationship between compound constituents, is another of the various factors of the morphological complexity of compounds to be taken into consideration when examining compound processing (Boutonnet et al., 2014). It should be noted that headedness varies across languages, as compound words can be head-initial or head-final (Williams, 1981). Additionally, the head does not always carry important semantic information (Inhoff, Starr, Solomon, & Placke, 2008). In certain languages, such as English, compound words tend to be right-headed; the final constituent determines, for the most part, the compound's meaning (e.g. *birdhouse*). In this situation, the initial constituent, then, acts as the modifier. This is similar to the relationship between an adjective and a noun in a noun phrase (Boutonnet et al., 2014). Priming studies (Jarema, Busson, Nikolova, Tsapkini, & Libben, 1999) between a compound and its morpheme constituents suggest that the head constituent accurately improves processing of compound words. Taken together, such findings strongly suggest that compounds are decomposed during reading. Additionally, they suggest that compounds are not represented as a whole unit in the mental lexicon, with the exception of compounds consisting of semantically opaque constituents (Boutonnet et al., 2014). These findings, however, do not put to rest the ongoing debate regarding decomposition during compound word processing, as it remains undetermined whether whole-word processing or whole-word representation is present for all kinds of compounds (Janssen & Caramazza, 2008; Kuperman, Bertram, & Baayen, 2008), or whether compound decomposition occurs even for strictly opaque compounds (Blanken, 2000).

**Frequency**

Studies have also taken into account the frequency of a compound during processing. Blanken (2000) found that the frequency of the individual constituents of a compound and not the frequency of the compound as a whole influenced the production of German nominal compounds in a naming task performed by German speakers with aphasia. Constituents with higher frequencies were more easily named than constituents with lower frequencies. It should be noted that the frequency of the first constituent was shown to have an especially strong effect in accessing the compound word as a whole. These findings are in line with the decompositional account of morphological processing in speech production (Blanken, 2000).

**Mental representation of compound words**

It is often assumed that compounds are simply words composed of words themselves. However, studies indicate that compound composition cannot be defined in such simplistic terms, at least for the majority of lexicalised compounds (Libben, 2014). Instead, Libben (2014) touches on the psycholinguistic study of compound processing, examining the psychological domain of the mental representation of compounds. Research has left little doubt that the mental representation of compounds constitutes both a whole word representation and a constituent lexeme representation. This is a departure from some of the early psycholinguistic notions that claimed that compounds were represented solely in terms of their constituents and that processing involved a prelexical decomposition of compounds into their respective constituent morphemes (Taft & Forster, 1976; Libben, 2014). These earlier notions of decomposition assumed that even the most common compounds are decomposed and then recomposed every time they are perceived and produced, resulting in very low computational efficiency. New research by Libben (2014) argues that the constituents belonging to a compound word are actually represented in the mental lexicon as new lexical representations; representations different than their independent monomorphemic counterparts. Such representations are linked to specific positions and morphological roles (e.g. modifier, head) within a given compound word. The existence of these additional connections within the mental lexicon facilitate compound word processing, as the lexical network creates a more efficient method of processing lexical knowledge (Libben, 2014). In terms of the model proposed by Levelt and Meyer (1999), the constituents of a compound word would have separate lemma representations specifying their syntactic-semantic relationship with each other.

## Compound word processing in varying tasks

### Lexical decision tasks

Lexical decision tasks (Ji, Gagné, & Spalding, 2011) provide insight into the processing speed of morphologically complex words. Researchers (Ji et al., 2011) examining the processing of English compound words have suggested that if compound words are processed in a nondecompositional manner, lexicalised (e.g. *teacup*) and novel (e.g. *tombnote*) words should be processed differently. However, the presence or absence of a presumed compound structure should not have an effect on lexical decision processes based on the whole words (Fiorentino, Naito-Billen, Bost, & Fund-Reznicek, 2014). Results from both response time and electrophysiological experiments (Fiorentino et al., 2014) involving the processing of English compound words have found that response times to lexicalised compound words were faster than to monomorphemic word counterparts. Response time to novel compound words in lexical decision tasks was significantly slower than to unstructured nonword counterparts. Such electrophysiological results support the notion of morpheme-based processing of both lexicalised and novel

English compound words that were visually presented. In sum, both response time and electrophysiological results support the claim for morphological decomposition, refuting models that suggest that putatively complex words are processed via their wholes (Fiorentino et al., 2014).

Research coupling magnetoencephalography (MEG) with visual lexical decision tasks (Fiorentino & Poeppel, 2007) has provided further insight into the process of morphological decomposition in compound words. Specifically, researchers were interested in determining the processing differences between compound words (e.g. *teacup*) and single words (e.g. *crescent*) with the use of pseudomorphemic nonwords (e.g. *crowskep*) as controls. Findings supported a lexical processing proposal that maintains early decomposition of morphologically complex words into individual constituents; response times were faster for compound words than for matched single words and pseudomorphemic nonwords. Differences in the behavioural data also provide support for the idea of compound words having structured, internal representations based on the constituent morphemes. MEG data showed significantly earlier peak latencies for compound words than for single words, indicating constituent activation at the morpheme-level (Fiorentino & Poeppel, 2007).

Additional support for the presence of morphological decomposition for English compound words has been found using lexical decision tasks (Ji et al., 2011) designed to examine the role of transparency on processing speed. Results showed semantically transparent compounds (e.g. *rosebud*) and semantically opaque compounds (e.g. *hogwash*) to be processed at a faster rate than matched monomorphemic words (e.g.

*giraffe*). However, it is noteworthy that when decomposition/integration was encouraged by inserting a space into the compound words, the faster processing rate for semantically transparent and opaque words disappeared. This finding implies that, when prompted by complex structure, morphological decomposition makes both the lexical and semantic representation of compound constituents available for immediate processing. This result was found regardless of semantic transparency of the compound. Morphological decomposition then appears to result in an attempt at meaning composition, which facilitates transparent compound processing, yet burdens opaque compound processing due to the fact that the meaning computed from the constituents of an opaque word conflicts with its retrieved meaning (Ji et al., 2011).

Another study (Marelli & Luzzatti, 2012) addressed the role of headedness as well as semantic transparency during constituent access. Participants completed a lexical decision task involving nominal compound words. Findings shed light on the importance of the semantic and structural properties of compound words during lexical access. Significant interactions between constituent-frequencies, headedness and semantic transparency were found, suggesting that frequency aids in the processing of transparent and head-final compound words. These findings offer further support for the multi-route model of compound word processing while highlighting the importance of a semantic route whose role is to form conceptual combinations of constituent meanings (Marelli & Luzzatti, 2012).

Additional eye-tracking experiments (Kuperman et al., 2009) have contributed to the field of compound word processing, offering support for the multi-route model of lexical processing. Participants were presented with multimorphemic Dutch compound words in isolation while having their eye movements registered. Results indicated that full forms of compound words (e.g. *dishwasher*) and their constituent morphemes (e.g. *dish*, *washer*, *er*) played a role in compound word processing. In addition, morphological families of constituents (sets of compound words that share a constituent) had an effect on compound word processing; larger morphological family sizes facilitated compound word recognition. Greater compound word frequency, left and right constituent frequencies as well as larger left and right constituent family sizes facilitated compound word recognition. Constituent frequency and family size effects may contribute at the form processing level, the semantic processing level, or both. At the form level, readers may recognize a constituent based on its frequency (how often they have encountered it in a natural setting), whereas the effect of morphological family may be shaped by the reader's experience with recognizing the constituent as a part of the whole word form. This may speed up lexical search by excluding all other word competitors, providing a short-cut to the morphological families. At the semantic level, a constituent's frequency may reflect how easily accessible its meaning is. Finally, the family size of a given constituent would be an indication of how much activation the constituent morpheme induces within its morphological family network in the mental lexicon (Kuperman et al., 2009).

Taken together, findings from lexical decision tasks employing compound words have provided valuable insight into the manner of compound word processing. An undeniable body of evidence (Kuperman et al., 2009, Marelli & Luzzatti, 2012) refutes models that claim morphologically complex words are only processed via their full forms and supports the multi-route model of compound word processing with support for early decomposition of morphologically complex words (Fiorentino & Poeppel, 2007). Morphological decomposition makes both lexical and semantic information available for efficient processing (Ji et al., 2011) with variables such as whole word and constituent frequency, constituent family size (Kuperman et al., 2009), headedness and semantic transparency affecting ease of processing (Marelli & Luzzatti, 2012).

**Picture and word naming tasks**

Picture and word naming tasks are another methodology that has been used by researchers (Marelli, Aggujaro, Molteni, & Luzzatti, 2012; Marelli, Zonca, Contardi, & Luzatti, 2014; Semenza, Arcara, Facchini, Meneghello, Ferraro, Passarini, Pilosio, Vigato, & Mondini, 2011) interested in exploring the manner in which compound words are processed in the mental lexicon. In an investigation of headedness effects (Marelli et al., 2012), Italian patients with neglect dyslexia participated in a word naming study that explored whether compound constituents are organized in a hierarchical manner in the mental lexicon, while not ruling out the possibility of full form representation. Neglect dyslexia is an attentional disorder in which patients are unaware of part of their visual field and make mistakes when reading single words, sentences and texts. Such mistakes usually only affect one side of the stimuli. Most often, patients neglect the leftmost side, which was also the case for patients in the study by Marelli and colleagues. Stimuli were selected based on headedness: both left-headed (e.g. *pescespada*, swordfish, literally fishsword) and right-headed (e.g. *astronave,* spaceship) and non-word (e.g. *pestespada,* plaguesword) Italian compound stimuli were used. Scalise (1984) has argued that Italian compound words are predominently left-headed. However, this argument has since been challenged (Schwarze, 2005). Findings indicated a significant effect of headedness: left-headed compound words were read more accurately than right-headed compound words by these patients neglecting the left side (Marelli et al., 2012). An explanation for this effect includes a proposal that head and modifier constituents have different representations in the mental lexicon (Marelli et al., 2012; Semenza et al., 2011). Researchers suggest that readers' attention is captured by the compound word's head once implicit reading of the whole word is complete. This, in turn, suggests that a top-down process facilitates processing of the head, making it easier to process relative to the modifier (Semenza et al., 2011).

Another study examining the role of compound headedness in lexical processing (Marelli et al., 2014) used a picture naming task administered to participants with aphasia. This picture-naming task consisted of Italian compound words with head-initial (e.g. *pescespada*, swordfish, literally fishsword) and head-final (e.g. *autostrada*, highway, literally carroad) forms. Results showed a significant interaction between headedness and constituent position: the modifier proved to be more difficult to retrieve than the head, but this was only the case for head-final compounds. Ultimately, these findings support the notion that compound headedness is represented at central processing levels (Marelli et al., 2014).

Some evidence also suggests that underlying processes responsible for compound word processing differ from those of compound word production. A study employing two picture naming tasks (Janssen & Caramazza, 2008) found that compound word production in English and Mandarin Chinese was affected by the compound's whole word frequency and not its morpheme frequency. These findings were interpreted to support a single-stage model of lexical retrieval which postulates only one lexical layer (i.e., no lemma layer) between the phonological and semantic properties of a word (Caramazza, 1997) and are further supported by studies employing response-association tasks (Chen & Chen, 2006).

**Sentence processing tasks**

Additional sentence processing tasks (Juhasz, 2012; Matzen & Benjamin, 2009; Pollatsek, Bertram, & Hyönä, 2011; Service & Maury, 2015; Service & Tujulin, 2002) have provided additional insight into how morphologically complex words are processed in the mental lexicon. In one study (Pollatsek et al., 2011), participants read sentences containing novel and lexicalised two-constituent Finnish compound words while having their eye movements measured. Gaze durations on the target word were significantly affected by lexicality and first constituent frequency, with gaze duration longer for novel compound words and first constituents with a lower frequency. This implies that first constituent frequency affects compound processing in two different stages: in the initial compound encoding as well as during the construction of meaning for the novel compound words (Pollatsek et al., 2011).

An additional study (Juhasz, 2012) that measured eye movements during reading tasks with compound words investigated the influence of sentence context on morphological processing. English compound words were selected based on their first lexeme frequency and final lexeme frequency. They were embedded into sentence contexts which either predicted the compound word or were neutral in prediction of the compound word. Results found predictable sentences diminished the effect of the first lexeme frequency on both first fixation and single fixation durations. These findings support theories that highlight the importance of morphology at various levels within a reader's mental lexicon, indicating that sentence context affects access to early morpho-orthographic processes. Ultimately, this study provides evidence for an interactive relationship between word recognition and sentence context (Juhasz, 2012).

Overall, research examining the representation of compound words in the mental lexicon using tasks such as lexical decision, naming and sentence reading, supports the notion that compound words are processed via morphological decomposition (Fiorentino et al., 2014; Fiorentino & Poeppel, 2007; Ji et al., 2011; Juhasz, 2012; Kuperman et al., 2009; Marelli et al., 2012; Marelli & Luzzatti, 2012; Matzen & Benjamin, 2009; Pollatsek et al., 2011). Specifically, lexical decision tasks (Ji et al., 2011) have shown that morphological decomposition takes into account a compound word's lexical and semantic representation in the mental lexicon. In addition, word naming tasks (Marelli & Luzzatti, 2012) show that a compound word's frequency aids in processing transparent and (at least in Italian) head-final compound words, while left-headed compound words are generally read more accurately than right-headed compound words. These findings suggest differential representations for head and modifier constituents in the mental lexicon (Marelli et al., 2012; Semenza et al., 2011). Sentence reading experiments (Pollatsek et al., 2011) have also shown first constituent frequency to affect compound word processing in Finnish. Picture naming tasks (Marelli et al., 2014) have demonstrated that modifier constituents are in fact more difficult to retrieve for production than head constituents, but only for head-final Italian compound words. Thus, compound headedness appears to be represented at central processing levels. Finally, sentence context affects how memory words are encoded in memory (Matzen & Benjamin, 2009) as well as access to early morpho-orthographic processes, suggesting an interactive relationship between word recognition and sentence context (Juhasz, 2012). Taken together, such findings hint at which variables may be influential in a study investigating memory recall of compound words in varying reading span tasks.

**Memory for morphologically complex words**

To date, morphology has not been a large topic of interest in studies employing memory. However, there have been a few studies that have questioned morphology's role in memory recall tasks (Service & Maury, 2015; Service & Tujulin, 2002; Németh, Ivády, Guida, Miháltz, Peckham, Krajcsi & Pléh, 2011). Research conducted by Service and Maury (2015) and Service and Tujulin (2002) has examined the effects of morphological complexity in Finnish on recall of word sequences in different WM tasks. They found memory load effects of both derivation and inflection. Results also suggested that different classes of complex word forms are all processed differently, especially when participants are allotted more or less rehearsal time. Specifically, derived words like *boy+hood* were more easily recalled in a reading span task when the time to rehearse them before the next sentence began was shorter whereas there was no effect of pause length before the next sentence on monomorphemic base words like *boy*. This indicates that representations vary based on word type and presents a challenge for theories of how meaning and form interact with cognition to allow language comprehension (Service & Maury, 2015; Service & Tujulin, 2002). Another recall study (Németh et. al., 2011) investigated the relationship between the morphological complexity of words and verbal short term memory (STM). Recall items were composed of two lists: Hungarian two-syllable stems (base words) and two-syllable morphologically complex words (stem + suffix). An additional experiment used three-syllable words. Findings indicate that STM span is significantly negatively affected by morphological complexity. Memory recall was better for derived words like *boy* + *hood* than inflected words like *boy* + *s*. Memory recall was also better for words with a regular morphological structure (*szú*, wormwood) compared to an irregular one (*szuv* + *ak*, wormwood + pl, ‘wormwoods’). These results are in line with Service and Tujulin’s study (2002), with suffixed words being more difficult to recall than stem words when presented both visually and auditorily. This finding can be explained by the notion of chunking information into smaller parts (Chase & Simon, 1973; Gobet, Lane, Croker, Cheng, Jones, Oliver, & Pine, 2001). Chunking decomposes a morphologically complex word into multiple morphemes, each occupying space, which results in fewer resources being used in STM. It also indicates a cost for processing irregular forms (Németh et al, 2011).

To add to these findings is a study (Matzen & Benjamin, 2009) that explored how sentence context predicts various patterns of false memories for compound words in recognition tasks. Results from such studies provide information about the nature of encoding strategies in various contexts as well as the nature of memory errors. In one experiment, compound words that created a conjunction lure (e.g. *tailspin* and *floodgate* → *tailgate*), were presented either as single words or embedded within sentences. At the end of each set, a compound word (either old, new (unrelated) or a semantic lure) appeared and participants had to decide whether the compound word had been previously presented or not. Results showed that when stimuli had been presented within a sentence context, participants were less likely to make conjunction lure errors but more likely to make semantic lure errors, whereas the opposite was found for stimuli presented as single words. The authors' explanation for this finding was that different encoding strategies are used during tasks in which memory words are embedded in or out of a larger meaningful context. Focusing on words' surface features and less on the semantic properties aids in rejection of semantic lures that do not match the original word forms (Matzen & Benjamin, 2009).

The present study was designed to investigate how compound words are represented in STM in immediate serial recall tasks and in WM in complex span tasks that combine processing and storage demands. In the simple span task, storage demands are the result of having to encode compound words into a memory list in the absence of sentence processing demands. In the complex span tasks, the combined processing and storage demands are the result of having to encode compound words into a memory list in the presence of sentence processing demands. We have incorporated a sentence reading task into the complex span tasks as a secondary processing task. In this way, participants cannot focus solely on encoding and maintaining stimuli. Attentional resources must be shared across tasks. The following section is an introduction and review of the current models of maintenance mechanisms of verbal information in STM tasks and WM tasks that include processing components.

**Maintenance mechanisms of verbal information in short term memory tasks**

Working memory (WM) tasks as well as short term memory (STM) tasks require retention of information over the short term, making these two memory processes closely related. The difference lies in the cognitive processes involved: the most common STM tasks, known as simple span tasks, are comprised of only storage and immediate serial recall of a limited number of items, whereas WM span tasks, also known as complex span tasks, are comprised of certain cognitive processing strains in addition to encoding and retrieval demands (Baddeley, 2012; Lewandowsky, Geiger, Morrell, & Oberauer, 2010; Unsworth & Engle, 2007). WM has most influentially been characterized by Baddeley and Hitch (1974), whose model of WM includes three components: the phonological loop, which will be described in this section as it is also considered a concept of STM, the central executive and the visuo-spatial sketchpad. More recently, the domain-general episodic buffer was added to the framework to bind together information from different modalities and long-term memory (LTM) (Baddeley, 2000). The WM model describes *the phonological loop* as a central concept within the WM framework. It is proposed to function as a temporary storage system for acoustic or speech-based information (Baddeley & Hitch, 1974). More specifically, it is described as a neural network which consists of representations of three kinds of information: lexical items, phonemes and a context/timing signal (Burgess & Hitch, 1999). Such information may be retained in the form of memory traces for 2 to 3 seconds before they fade away, unless refreshed by the act of rehearsal, which seems to employ a form of subvocal articulation. This subvocal articulation, in turn, keeps the memory trace alive. Thus, memory traces may be maintained, given that continuous rehearsal takes place and the number of items to be retained does not exceed maximum capacity, i.e. how much can be rehearsed in the time-window of 2–3 seconds. Items which are phonologically similar are more prone to recall errors in ordered recall as they have fewer phonologically distinguishing features within a list and lead to more confusions among items (Baddeley, 1996).

In addition to phonological form, words have meaning. Studies (Saint-Aubin & Ouellette, 2005; Saint-Aubin & Poirier, 1999) have shown significant positive and negative semantic similarity effects. The assumption is that semantic codes are active during phonological coding (Baddeley, 1966). Semantic codes have been found to have effects in tasks requiring immediate serial recall of noun-adjective pairs that displayed semantic compatibility (e.g., *priest-devout*) (Levy, 1971). An additional study (Baddeley & Ecob, 1970) used syntactically structured combinations with meaning and scrambled word strings (e.g. *my fine wine* vs. *wine my fine*) and discovered a predominance of phonological coding at short delays and semantic encoding after longer delays. Baddeley

(2012) argues that this indicates that performance in STM tasks employing verbal information might rely on both phonological and semantic coding. It is to be noted that in comparison to semantic encoding in standard tasks (i.e., immediate serial recall of unrelated words), phonological coding is fast and attentionally undemanding (Campoy, Castellà, Provencio, Hitch, & Baddeley, 2014). Semantic encoding in standard tasks is, contrarily, more difficult and takes relatively longer to establish. However, semantic encoding traces prove to be more durable (Campoy et al., 2014).

Early research (Shulman, 1970) using recognition tasks to investigate the relative effectiveness of semantic and phonemic encoding in STM predicted that slower presentation rates of individual words would encourage semantic encoding in STM. Indeed, it was found that semantic encoding in standard STM tasks takes longer to establish than phonological encoding in such tasks, indicating it is time dependent.

Being able to recall a novel sequence of items in the correct order is crucial for various higher-level cognitive functions (Hurlstone, Hitch, & Baddeley, 2014). Hurlstone and colleagues (2014) were interested in the mechanisms behind storing and retrieving a novel sequence of items. Based on an extensive literature review, they proposed that a competitive cuing mechanism is involved in selection of items from verbal, visual and spatial sequences in STM. This competitive queuing mechanism targets items that are simultaneously active in parallel, so that the strongest item is selected for output at recall. Specifically, the verbal STM competitive queuing mechanism is assumed to be affected by item similarity (e.g. phonological similarity), which is present during both serial order encoding and retrieval. It is yet to be determined whether their proposal can be extended from immediate serial recall to other memory tasks, such as free recall and complex span (Hurlstone et al., 2014). The following section reviews the various maintenance mechanisms of verbal information in WM tasks that include processing components. In addition to examining performance in simple span tasks, the present study is composed of complex span tasks with compound words as memory items in the presence of processing and storage demands.

## Maintenance mechanisms of verbal information in working memory tasks that include processing components

### Articulatory rehearsal

Various mechanisms for the maintenance of verbal information in WM have been proposed and subsequently revised in recent years since the first introduction of Baddeley and Hitch's (1974) model of WM. The central executive in this framework has been described by Baddeley (2000) as an "attentional controller" of WM as well as the "most important component of [WM]" (Baddeley, 2003), as it combines information from its slave systems (i.e. the phonological loop and the visuospatial sketchpad) into coherent episodes which are then available to be retrieved consciously. Although aided by the phonological loop and the visuospatial sketchpad via sensory input, the central executive lacks storage capacity in the newer formulations of the model. Its role is somewhat less understood than the other components of the WM model, however, its presence and function is crucial during immediate recall tasks (Baddeley, 2000).

**Attentional refreshing**

Based on recent empirical findings, a new model of the maintenance of verbal information in WM (Barrouillet, Bernardin, & Camos, 2004; Camos & Barrouillet, 2014) has been proposed, addressing WM function and structure as well as complex span related phenomena. This model, known as the Time-Based Resource-Sharing (TBRS) model (Barrouillet et al., 2004), follows the Baddeley and Hitch framework in positing that memory traces decay rapidly over the course of time. In dual tasks of the complex span type, memory items are presented interleaved between processing tasks. The attentional demands of the processing task can be measured as *cognitive load*, i.e. the proportion of time of all time available for task performance that the processing task occupies. As cognitive load of the processing (distractor) task increases, accuracy in memory recall in the concurrent storage task declines. However, time-based decay of the memory items can be avoided via active maintenance, such as attentional refreshing or articulatory rehearsal. The TBRS model addresses the role of attention in WM, suggesting that attention is involved in both the processing and maintenance of information. In addition, this model explains how attention is shared in a time-based manner between processing and maintenance of information in WM. However, it is not implied that attention is involved indefinitely in such WM processes; there are two maintenance systems, the phonological loop and refreshing relying on attentional resources, which aid storage in WM (Camos & Barrouillet, 2014).

The TBRS model proposes two systems which can be active during the maintenance of verbal information in WM. The first system is the phonological loop (Camos & Barrouillet, 2014), first proposed by Baddeley (1986). As mentioned earlier, its role consists of storing and maintenance of verbal information in phonological format with memory traces remaining active via subvocal rehearsal (Baddeley, 1996). The second system is the *executive loop*, which is comprised of an episodic buffer (Camos & Barrouillet, 2014), similar to the episodic buffer in Baddeley's model (2000) of WM, as well as a procedural system (Camos & Barrouillet, 2014). The executive loop is proposed to be a general attention-dependent maintenance system as opposed to the domain-specific system of the phonological loop (Mora & Camos, 2013). According to Camos and Barrouillet (2014), representations within WM are stored in a buffer. Here, they are subject to interference and temporal decay. As a result, damaged representations require reconstruction and reactivation. This is accomplished by the procedural system, which reads the representations and either maintains or updates information by initiating an appropriate production rule and is also able to switch between representations that are held in the episodic buffer. As guidance, the procedural system refers to the current WM goal in order to determine which representations are to be maintained active, using attentional refreshing (Camos & Barrouillet, 2014). This process of maintenance of verbal information in WM is comparable to that of the phonological loop in Baddeley's model (1983) of WM, which is also responsible for the maintenance of verbal information.

The functioning of the executive loop is based upon the four main proposals of the TBRS model. To begin, the processing and maintenance of information within the executive loop are both reliant upon attention. As attention is a limited resource, it must be shared between processing and storage. The second proposal is that the cognitive steps required to process and maintain information in WM occur one at a time; if the executive loop is currently engaged in a different process, it cannot maintain items currently in memory. The third proposal is that as soon as attention is distracted from the memory traces, decay causes the traces to deteriorate with time. It is, thus, assumed that during WM tasks in which there are distractors, such as in complex span tasks, attention is occupied by the processing of these distractors and, therefore, memory traces of the items to be recalled fade and become more difficult to access. The fourth and final proposal is that in order to share attention, focus is switched incessantly from processing to maintenance. This is a result of the attentional limit of one item at a given time as well as the time-related decay of memory traces that are not in the focus of attention. The assumption is that most tasks do not result in a continuous and unbroken stream of attention; it is possible to divert attention for short periods of time when needed and refocus attention back to the task at hand (Camos & Barrouillet, 2014).

To support and further validate the existence of the two TBRS maintenance systems, namely the phonological loop and the executive loop, Mora and Camos (2013) predicted that phonological effects which have been previously found to affect the maintenance of verbal information would be apparent under maintenance of the phonological loop but not under maintenance of the executive loop, as the two systems maintain information via different means, namely subvocal rehearsal and attentional refreshing, respectively (Mora & Camos, 2013). Such phonological effects previously found to effect the maintenance of verbal information include the phonological similarity effect, a phenomenon in which immediate serial recall performance is reduced when recall items are phonologically similar (e.g. *mad*, *man*, *mat*, *cap*, *cad*, *can*, *cat*) as opposed to phonologically dissimilar (e.g. *cow*, *day*, *bar*, *few*, *hot*, *pen*, *pit*) (Baddeley, 1966).

Another study (Camos, Lagner, & Barrouillet, 2009) has investigated the interplay between articulatory rehearsal and attentional refreshing as two different maintenance mechanisms of verbal information in WM. Using a complex span paradigm, researchers manipulated the degree of articulatory suppression as well as the attentional processing load in order to examine the different effects on the two maintenance mechanisms. Their findings indicated that both articulatory suppression and attentional demand negatively affect concurrent maintenance. They do not, however, interact, suggesting that articulatory suppression and attentional demand negatively and separately affect the two independent maintenance mechanisms (Camos et al., 2009).

**Evidence against temporal decay in working memory**

The introduction of a new model within any field of research is bound to conjure scrutiny and challenge in its design, as is the case with the TBRS model of WM. Researchers (Oberauer & Lewandowsky, 2014; Lewandowsky, Oberauer, & Brown, 2009) have challenged the TBRS model, suggesting that poor memory performance is mainly due to interference in WM. Evidence against the case of decay in WM has been fortified by various research findings which refute the assumption of time-based decay of item representations in WM and have extensively reviewed evidence supporting this view (Oberauer & Lewandowsky, 2014; Lewandowsky et al., 2009).

**The present study**

The present study investigates individual performance in memory recall of compound words in simple and complex span tasks. Specifically, it seeks evidence for decompositional processes in the two types of memory task. Effects based on constituent rather than whole word characteristics would indicate the presence of decomposition. Such effects could also inform us about the character (semantic, lexical, morphological etc.) of spreading of activation within neural networks, competitive cuing and selectional processes in different tasks and memory processes. To date, there has been little research exploring whether different memory processes (i.e. related to STM, WM and long term memory (LTM)) may be differentially sensitive to representation and processing aspects of compound words. More specifically, this study investigates the differences in compound word representation, and spread of activation in the mental lexicon, in immediate serial recall in simple span STM tasks and serial recall immediately following tasks designed to involve both processing and storage demands, i.e. in complex span WM tasks. The simple span STM task is comprised of solely a list of memory words presented at a relatively fast rate and to be recalled immediately after presentation. There are two complex span WM tasks that vary in the presence of a pause after presentation of each memory word and before onset of the following distractor sentence for processing. The absence of a pause was intended to minimize opportunity for subvocal rehearsal, whereas the presence of a pause along with appropriate instructions encouraged rehearsal. This design allowed an investigation into different memory processes involved in representation and processing aspects of compound words, and how differentially sensitive memory task types are to lexical variables. Lists of memoranda were manipulated so that each set (list) of four compound words contained one “lure” pair (e.g. *pinstripe* + *warhead* = *pinhead*) in which the modifier and head constituents from separate compound words could recombine to form a new, legal word. The intention was to increase chances of recombination to determine what kind of lexical variables result in greater recombination likelihood and what kind of tasks are more likely to show such patterns.

If phonological activation in subvocal rehearsal increases the probability of decomposition, we predicted that performance in the presence of rehearsal opportunity in a complex span task might be worse compared to complex span in the absence of rehearsal opportunity. Such a result would also be in line with previous findings on morphologically complex Finnish words (Service & Maury, 2015; Service & Tujulin, 2002 . This poorer performance may be characterized by more recall errors and omissions. However, it is also possible that results from the present study using compound words in English will not mirror those of previous experiments (Service & Maury, 2015), in which monomorphemic, inflected and derived words were used as stimuli. It is possible that inflected, derived and compound word forms in a language are all processed differently according to allotted rehearsal time (Service & Maury, 2015). In comparing the present three tasks, we predicted that time constraints in two conditions (simple span and complex span no pause) would prevent phonological rehearsal of the compound word constituents leading to generally poorer memory (Shulman, 1970). However, more recombinations would be seen in simple span and complex span with pause. Since compound words like *drumstick* and *candlelight* are each comprised of two semantically-independent constituents, it is expected that recall errors will be made based on phonological encoding of the constituents, sometimes leading to recombination of the two parts of a compound word, e.g. *candlestick*. However, as all items would have been very recently encoded into a memory episode in simple span, recall could still be expected to be relatively good. On the other hand, we predicted rehearsal opportunity in complex span (complex span with pause condition) would result in both phonological and semantic encoding of compound word constituents, leading to fewer errors overall compared to the condition without pause.

We chose our stimuli to represent the full range of various lexical variables. We thought memory effects of lexical variables would reveal differential consequences of competition between items within list, mental lexicon activation and ease of binding a set of compound words to a list representation for recall. We expected semantic transparency, frequency and family size to play a role in the types of recall errors made. Specifically, we predicted highly transparent words to be more vulnerable to decomposition. Lexical decision tasks (Sandra, 1990) have shown that transparent compounds (e.g. *beanpole*, *teaspoon*) are processed through morphological decomposition. Additionally, constituent morphemes of completely opaque compounds (e.g. *bootleg*) do not exhibit a connection with one another at a level of semantic representation (Zwitserlood, 1994). Therefore, they may be less susceptible to recombination errors as semantic relatives are less likely to be activated within the neural network. We predicted compound words with higher constituent and whole word frequencies to be more easily recalled overall, as supported by naming tasks (Blanken, 2000) and eye-tracking studies (Kuperman et al., 2009). Finally, contrary to studies that found that constituents with larger morphological family sizes were more easily recognized than those with smaller morphological family sizes (Janssen & Caramazza, 2008; Kuperman et al., 2009) we predicted that compound constituents with larger morphological family sizes would result in the compounds they were included in to be harder to recall. We reasoned that such words would be more susceptible to decomposition and recombination, as competing semantically related words may be activated within the neural network, leading to recall error.

## Methods

### Participants

Thirty-one university students (5 males) between the ages of 18 and 23 (mean = 19.8; SD = 1.25) were recruited through the McMaster Linguistics Research Participation System. All participants were native speakers of English. Ten self-reported as monolingual with the remaining 21 speaking at least one additional language, at varying levels of fluency. A consent form approved by the McMaster Research Ethics Board (See Appendix p. 68, Consent form) was administered and completed prior to data collection. Following data collection, participants were debriefed on the study's research questions

(See Appendix p. 71, Debriefing form). Participants were granted experimental credit for their participation.

**Stimuli and experimental conditions**

Eighty experimental sentences and twenty comprehension questions were composed for the two complex span tasks. These sentences and questions were designed to result in WM storage and processing demands during the complex span tasks. Sentences were adapted from Chapman, Service, Kuperman & Deschamps (in preparation). All sentences had the same syntactic structure: a definite, animate subject NP, a past tense verb and a definite object NP. All sentences were five words in length (e.g. *The dolphin broke its fin*). One hundred and twenty concatenated, noun-noun, head-final target compound words were selected from the CELEX English Database (Baayen, Piepenbrock, & van Rijn, 1995) for the two complex span tasks and the one simple span task. It was ensured that the memory words represented a uniform distribution of whole word transparency values (*M* = 0.18, *SD* = 0.12). There were four target compounds to memorize in each set, two of which were strategically chosen as a “lure pair” (e.g. *candlelight* and *drumstick* = *candlestick*). The simple span task consisted of 10 lists, each containing four target compound words, also including a lure pair. Each compound within the lure pair consisted of either a head or a modifier that could decompose and recombine to create an entirely new lexicalised compound. We tried to ensure that none of the heads or modifiers within all three tasks, besides the lure pairs, could decompose to create new and legal compound words within or across sets.

Each of the two complex span tasks consisted of 10 sets, each containing a set of four sentences. One yes/no comprehension question pertaining to one of the sentences appeared at the end of each set (e.g. *Did the baby steal the candy?*). The comprehension questions were administered to ensure participants were reading and processing each sentence and not focusing solely on the memory task. To avoid order effects, the compound lures' location within the sets was also controlled: the compound containing the modifier lure appeared first within 50% of the lists and the lure pair's position within the list of four words was randomized (e.g. the lure pair did not always appear in the first two positions, etc.). We also controlled for the comprehension questions' target sentence locations within the sets of each complex span task. Finally, each of the three tasks had a reversed-order variant resulting in a total of three task variant pairs. Each participant was administered either the original order tasks (variant A) or the reversed order tasks (variant B). The order in which the three tasks were administered to participants was randomised and controlled (e.g. the simple span task was not always administered first, etc.).

**Procedure**

Testing took place at the McMaster Language Memory and Brain Lab in Togo Salmon Hall. The procedure lasted approximately 45 minutes. Task instructions were presented on white letter-size (21.59 x 27.94 cm) paper, in Lucida Sans font (size 18). All instructions were printed in black font except for the mention of target compounds, which were printed in capital red font, to look like they appeared on screen in the experiment. Visual stimuli were presented on an iMac computer screen, placed approximately 50 cm from the participant. The experiment was programmed using SuperLab.

In the complex span tasks, sentences were presented one word at a time for 500 ms each in Lucida Sans font (size 18) in black font on a white background. A target compound word was presented after each of the sentences in Lucida Sans font (size 18) in capital, red letters for 1500 ms. After the target word the first word of the following distractor sentence appeared. Comprehension questions were displayed on a single screen in the same font and size after a full set of four sentences and target words. Participants were asked to answer the comprehension question by pressing Y for "Yes" and N for "No"). The end of each set of four was marked by a screen prompting participants to answer a comprehension question. Once answered, a screen prompted participants to recall, out loud, the target compounds in the order in which they had appeared.

The two complex span tasks varied in either the presence or absence of a pause after presentation of each target compound that had to be memorised. In the no pause condition, the target compounds were immediately followed by either the first word of the following sentence, or, at the end of the set, by a comprehension question. In the pause condition, the target compounds were followed by a 2000 ms pause before onset of a sentence or comprehension question. In the no pause condition, participants were instructed to forgo rehearsing words to themselves, as the lack of a pause would not allow them to do so. In the pause condition, participants were encouraged to utilise the pause to rehearse the words in their head.

In the simple span task, target compounds were presented one at a time in Lucida Sana font (size 18) in capital red letters for 1500 ms. There were no pauses between words. The end of each set was marked by a screen prompting participants to recall, out loud, the target compounds in the order in which they had appeared, as this task did not contain sentences or comprehension questions.

All participants performed each of the three tasks. Participants performed three practice trials before the test trials began in order to become familiar with the procedure. These trials were not included in the analysis. The practice trial target words were not compound words. However, they each consisted of two to three syllables to mimic the length and phonological complexity of the target compounds. Participants were informed that if they required a break, they were permitted to stop between trials and/or between tasks. Experiment order was included as a factor in the statistical analyses, as slightly more participants received variant A of each task.

**Results**

For each set, the total number of words correctly recalled was scored for both the total number (i.e., position of the words recalled within a set did not matter) and for strict serial order (only words recalled in the correct position were considered correct). Overall mean item recall ($M$ = 2.10, $SD$ = 1.07) was similar to the overall mean serial recall ($M$ = 1.99, $SD$ = 1.12). As serial scoring is a more conservative measure of item recall, serial scores are reported. Mean recall for memory items in the simple span condition (*M* = 2.16, *SD* = 1.16) and the complex span pause condition (*M* = 2.16, *SD* = 1.09) appeared to be similar and better than recall in the complex span no pause condition (*M* = 1.64, *SD* = 1.02) (see Figure 1).

Generalized linear mixed effects multiple regression models (Baayen, Davidson, & Bates, 2008; Baayen, 2008) with participants and memory words as random effects were used in the main analysis, as variance between words as well as participants result in random effects in verbal recall. These models were run using the lme4 package for R (version 3.2.3, R Core Development Team, 2015). These models allow for simultaneous investigation of covariates characterizing words as well as individual subjects, thus accounting for any variance between both items and participants. A logistic regression statistical model was used since the dependent variable that was investigated in the mixed model analysis had a binomial distribution; participants were given a score of 1 if the memory word was correctly recalled and 0 if they failed to recall the memory word correctly or if there was an omission. A likelihood ratio test was used to determine which random effects significantly improved the model's performance, allowing the model to be trimmed down from an initial maximal random-effects structure (Barr, Levy, Scheepers & Tily, 2013). Using the likelihood ratio test, fixed effects that were not found to significantly improve performance of the model were removed. The reported figures show the fixed and random effects which were kept in the final models once the elimination and trimming process was complete.

A main question of this study was whether task type affects memory recall performance (simple span vs. complex span no pause vs. complex span with pause). Of additional interest was whether there was a serial position effect, as memory words were presented in sets of 4, either one after each sentence (complex span) or as an uninterrupted list (simple span). Practice, fatigue and other effects developing over trials were modelled as a set number effect; each of the three tasks contained 10 sets of 4 memory words. In order to control for set effects, sentences in any given set were coded with the same value and normalized into z-scores. Lastly, normalized order of the task type was taken into consideration before the final model was fitted. Results from this statistical model display a significant main effect of task type (see Figure 1):

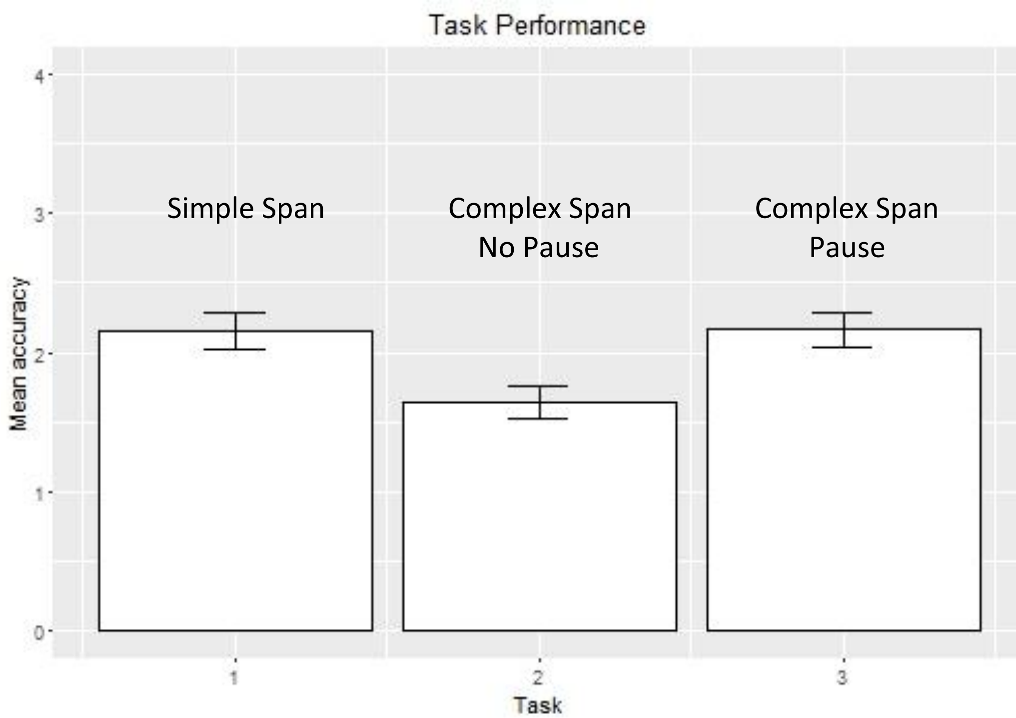



**Fig. 1.** Mean recall accuracy within set by task type. Error bars represent 95% confidence intervals.

mean recall accuracy within a set was significantly higher in both the simple span task ($\beta = 0.645$, SE = 0.170, $z = 3.80$, $p < 0.001$) and in the complex span pause task ($\beta = 0.634$, SE = 0.170, $z = 3.744$, $p < 0.001$) when compared to the complex span no pause task. Recall performance in the complex span pause task (54.16% recall accuracy) was only very slightly better than in the simple span task (53.65% recall accuracy) and the contrast was of no statistical significance (at the 0.05 level). Recall performance in the complex span no pause task (41.44% recall accuracy) was poorest of all three tasks. In addition, a significant effect of set number within the experiment was found; participants were more likely to recall a memory word correctly at the end of the experiment ($\beta = 0.140$, SE = 0.039, $z = 3.64$, $p < 0.001$). Also, a significant effect of memory word serial position within a set was found; participants were less likely to recall a memory word correctly towards the end of a set of 4 memory words ($\beta = -0.666$, SE = 0.069, $z = -9.721$, $p < 0.001$) compared to memory words at the beginning of a set, as shown in Figure 2. One-way repeated measures analysis of variance (ANOVA) showed no significant main effect of Experiment Version (original vs. reversed order of trials), $F(1,8) = 1.09$, $p = 0.30$ or Set Order $F(1,7) = 0.07$, $p = 0.79$.

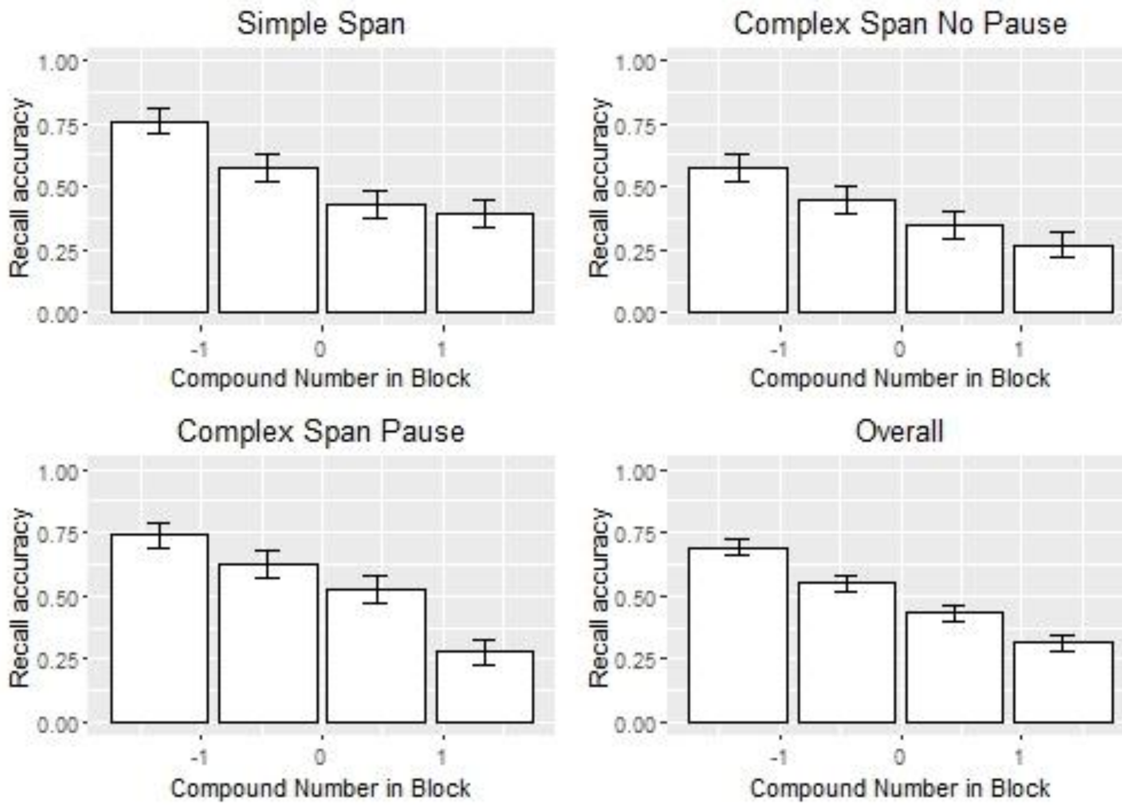



**Fig. 2.** Recall accuracy of memory word according to position by task type. Error bars represent 95% confidence intervals.

An important question of this study was whether lexical characteristics of the compound words affect memory recall performance. Compound word lexical variables were included as regressors in generalized linear mixed effects multiple regression models in a further analysis of recall performance. All but one of the lexical variable values were derived from the CELEX English database (Baayen et al., 1995). Entropy values were derived from Schmidtke, Kuperman, Gagné, & Spalding (2016). Lexical variables included three compound frequency values (whole word, modifier (left constituent) and head (right constituent)), entropy of the relational distribution of the compound word, and the morphological family sizes of the left and right constituents (the number of word types that also contain the left or right constituent of the target compound word), respectively. Also included were three semantic transparency values (transparency of the whole word, the semantic similarity of the modifier to the whole compound word (modifier-compound, e.g. *snow – snowfield*) and the semantic similarity of the head to the whole compound word (head-compound, e.g. *way* and *railway*). Latent Semantic Analysis (LSA, Landauer & Dumais, 1997) is a measure of co-occurrence that is also used as a measure of semantic transparency (e.g. Kuperman & Bertram, 2013; Marelli & Luzzatti, 2012; Marelli et al., 2014). LSA measures semantic transparency as the degree of semantic similarity between pair-wise relations (which is of relevance to the present study): the head and the whole compound word (e.g. *wash* and *carwash*), the modifier and the whole compound word (e.g. *car* and *carwash*), and the head and the modifier of the compound word (e.g. *car* and *wash*) (Landauer & Dumais, 1997). Right constituent (head) frequency, entropy and right constituent family size did not result in significant recall error effects and are not discussed further.

A significant main effect of compound word frequency was found: a higher compound word frequency predicted a higher rate of memory recall ($\beta = 0.308$, SE = 0.061, $z = 5.026$, $p < 0.001$). A main effect of left constituent (modifier) frequency in the opposite direction was also found: a higher left constituent frequency predicted a lower rate of memory recall ($\beta$ = - 0.115, SE = 0.062, $z$ = - 1.843, $p$ = 0.05). (Models failed to converge when an interaction with task was included).

**Error analysis**

This study was also designed to investigate the types of recall errors made as a function of lexical variable values. Pooled response distributions were initially compared between memory tasks using Chi-square analyses of counts of correct responses and responses in different error categories (see Table 1 for description of error categories). A significant difference in response distributions was found across the three task types, $\chi^2(12) = 97.37$, $p < 0.0001$. Based on individual cell contributions in the contingency table, these differences were caused by: a significantly smaller than expected proportion of correct responses in appropriate serial positions in the complex span no pause task compared to both the simple span and complex span pause tasks, a smaller proportion of one-constituent errors in the complex span pause task and a larger proportion in the simple span task compared to the complex span no pause task, a larger proportion of recombination errors with words not in experiment in simple span and a smaller proportion than expected in complex span with no pause, and, finally, a larger proportion of omissions in the complex span no pause task compared to both the simple span and complex span pause tasks.

**Table 1.** Totals of error types in experiment. Categories include *Recombination errors* (errors recombining two constituents to form either lure or non-lure word) and *Non-recombination errors* (all other errors, including omissions). The error analyses used fewer error categories than shown in Table 1: any recombination of modifier and head constituents (within or across sets), including lure constituents, were analyzed as *recombination errors*, incorrect order, incorrect set (list), incorrect, sentence word and constituent switch were analysed as *incorrect*, one constituent within set (list) and one constituent across sets (lists) were distributed accordingly into *incorrect head* or *incorrect modifier*. *Omissions* remained one category.

| **Recombination errors** | **Description** | **Total** |
|---|---|---|
| Lure | Recombination of lure constituents, e.g. *candlestick* from *candle*light and drum*stick* | 44 |
| Within set (list) | Recombination of non-lure constituents within set, e.g. *wolfhole* from *wolf*hound and fox*hole* | 30 |
| Across sets (lists) | Recombination of non-lure constituents across sets | 22 |
| Constituent reversal | Recall of head as modifier and modifier as head across target words, e.g., *craftmine* from *mine*shaft and space*craft* | 1 |
| | | |
| **Non-recombination errors** | **Description** | **Total** |
| Incorrect order | Target words recalled in incorrect order | 105 |
| Incorrect head | Incorrect recall of head, e.g. *waterfall* instead of *waterfront* | 59 |
| Incorrect modifier | Incorrect recall of modifier, e.g. *pincrew* instead of *aircrew* | 40 |
| One constituent within set | Recall of one constituent within set, e.g. *house something* instead of *houseplant* | 27 |
| Incorrect set (list) | Recall of target word from previous set | 21 |
| Incorrect | Non-categorizable | 20 |
| One constituent across sets (lists) | Recall of one constituent across sets | 5 |
| Sentence word | Recall of word from sentence | 5 |
| Constituent switch | Recall of head as modifier and modifier as head within target word, e.g. *songbird* instead of *birdsong* | 1 |
| Omission | Target word not recalled; participant said *blank* | 1,486 |

To understand the effect of task better, response distributions were also compared pairwise between the simple span and complex span no pause tasks. These two tasks had significantly different response distributions $\chi^2(6) = 68.52$, $p < 0.0001$. The differences were caused by: a larger proportion of omissions, and a smaller proportion of correct responses as well as lure recombination errors in the complex span no pause task compared to the simple span task. Although non-significant, a similar trend was found for non-lure recombinations and one-constituent errors, with more made in the simple span task than the  complex span no pause task. Response distributions were also compared *between the simple span and complex span pause tasks*. These two tasks had significantly different response distributions $\chi^2(6) = 22.01$, $p = 0.0012$. These differences were caused by a larger proportion of non-lure recombination errors and one constituent errors in the simple span task compared to the complex span pause task.

Overall, results indicate that error types reflecting decomposition of the compound words to their constituents (recombination errors with list words and other words , one-constituent errors) were more common in simple span than in complex span, whereas omissions were more common in complex span. Although not significant, order errors seemed more common when rehearsal was not possible or not encouraged (32.04%, 39.81%, respectively, of total order errors) compared to when rehearsal was encouraged (28.16%).

To be able to include lexical factors in the error analysis, linear mixed effects regression models were fitted to include log-transformed lexical variables of the compound words. These models aimed at testing whether such lexical variables elicit effects on the types of memory recall errors made, (see Table 1 with description of errors), according to task type. Models were run for each memory task and each error type of interest separately.

In simple span, rehearsal is unlikely but form representations probably remain in an active state. Results from the models exploring performance in the simple span task revealed a significant interaction between frequency and transparency: participants made significantly more recombination errors involving highly transparent compound words in the highest frequency band only ($\beta = 3.194$, SE = 1.315, $z = 2.428$, $p = 0.015$) (See Figure 3). It was also found that a larger left (modifier) family size predicted a higher rate of incorrect recall of the head constituent ($\beta = 0.042$, SE = 0.017, $z = 2.478$, $p = 0.013$) (e.g. responding with *snowflake* instead of *snowman*) (See Figure 4a). A higher left-right similarity (how frequently two constituents appear in the same context) predicted a lower rate of incorrect recall of the head constituent ($\beta = -5.752$, SE = 2.806, $z = -2.050$, $p = 0.040$) (See Figure 4b).

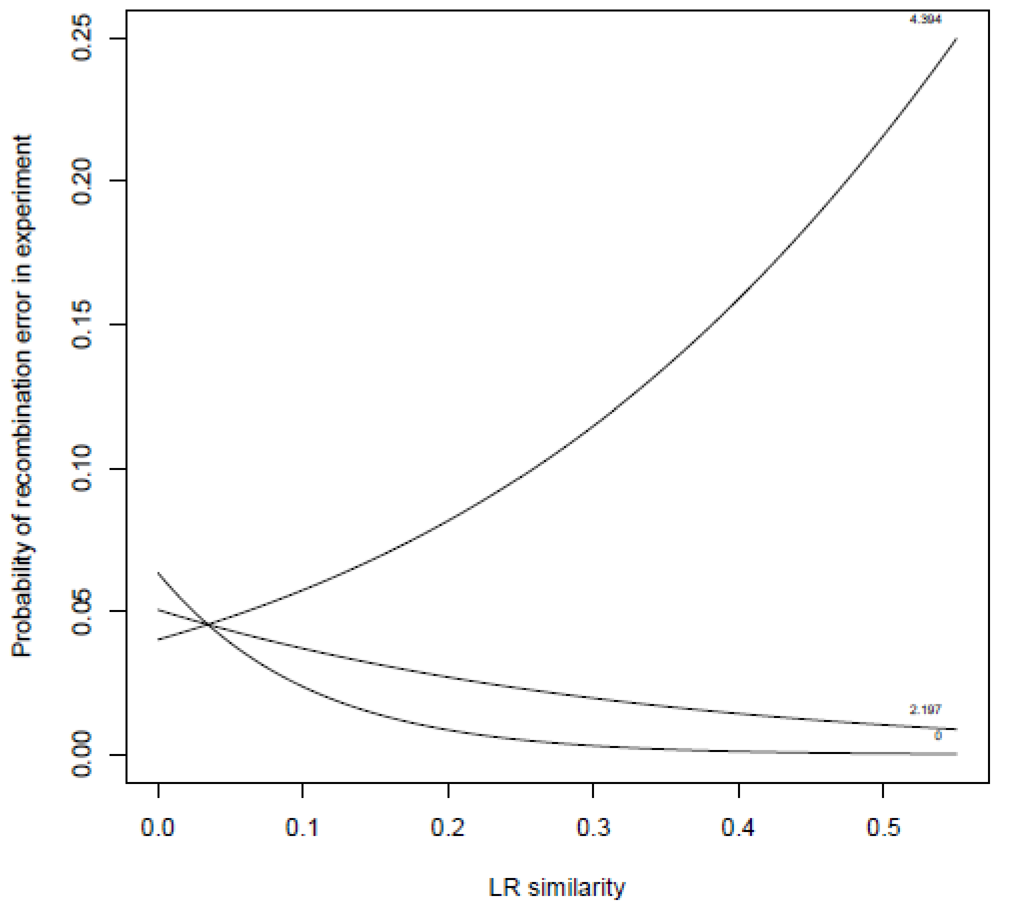
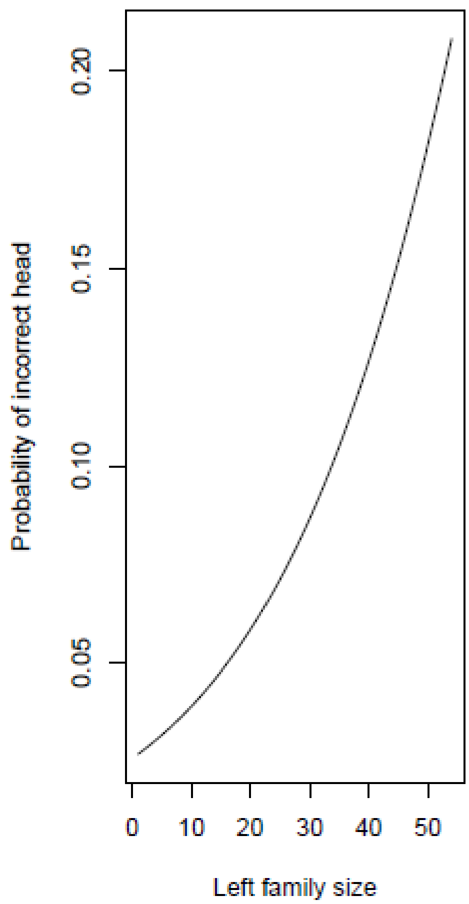



**Fig. 3.** Effect of Left-right similarity (how frequently two constituents appear in same context) on recall of recombination errors in simple span. Note that significantly more recombinations occur in compound words in the highest frequency band only.



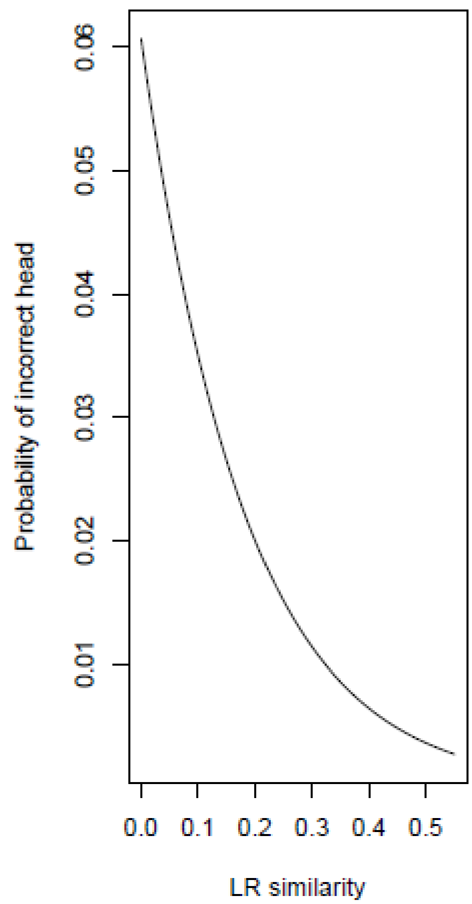




**Fig. 4a.** Effect of Left family size on recall of head (right) constituent.

**Fig. 4b.** Effect of Left-right similarity (how frequently two constituents appear in same context) on recall of head (right) constituent.

In the complex span no pause task, a representation of the word set had to be built over trials with intervening sentence processing. Because of time limitations, rehearsal was unlikely. Results for this task reveal that significantly fewer recombination errors were made towards the end of the experiment ($\beta$ = - 0.019, SE = 0.009, $z$ = - 2.221, $p$ = 0.026). However, this was not the case in the complex span pause condition with opportunity for rehearsal: the rate of recombination errors did not significantly change further into the experiment ($\beta$ = - 0.004, SE = 0.007, $z$ = - 0.628, $p$ = 0.530). None of the lexical variables significantly predicted recombination errors. Finally, lexical variables did not significantly account for recombination errors in the complex span with pause task, where rehearsal was encouraged, either.

**Comprehension questions**

In the two complex reading span tasks, participants were presented with a comprehension question at the end of each set of memory words. This ensured that participants were not focusing entirely on the memory task, as reading the sentences and answering the comprehension question at the end was an important part of the task. Participants were given a score of 1 if they answered the comprehension question correctly and a 0 if they answered incorrectly. Participants answered 60.7% and 62.7% of the comprehension questions correctly in the complex span no pause and complex span pause conditions, respectively. A significant main effect of task type was found: participants were more likely to answer the comprehension questions correctly in the complex span pause task ($\beta$ = 0.516, SE = 0.124, $z$ = 4.171, $p$ < 0.0001). A significant main effect of comprehension question order was found: participants were less likely to answer the comprehension questions correctly towards the end of the experiment ($\beta$ = - 0.109, SE = 0.048, $z$ = - 2.281, $p$ = 0.023).

## Discussion

The present study used compound words as memoranda in simple span and complex sentence reading span tasks in order to explore how WM and LTM interact in the recall of compound words (how word forms in the mental lexicon interact with word forms in focused attention) and what role word transparency, frequency and family size play in the type of recall errors made. More specifically, this study investigated memory recall performance in immediate verbal serial recall (simple span) and in two WM tasks involving the presence of processing and storage demands (complex span). The two tasks differed regarding opportunity for and explicit instruction encouraging rehearsal of memoranda. The effects of lexical factors on types of recall errors made according to task type were examined to conclude about the nature of the processing and retrieval of compound words in the mental lexicon during varying tasks which tax either short term or working memory.

### Effects of task type and rehearsal time on responses

This study investigated whether task type affects memory recall performance. Chi-square analyses and generalized linear mixed effects regression models indicated that performance in both item and serial recall in the simple span and the complex span pause tasks was significantly better than in the complex span no pause task. This finding is different from a previous finding for derived Finnish words (Service & Maury, 2015) in which morphologically complex words were more easily recalled in simple span than a variant of complex span that allowed rehearsal between trials. This finding suggests a disadvantage of complex span no pause relative to other conditions. Subvocal rehearsal was not encouraged in the complex span no pause task, as there was no allotted rehearsal time, whereas it was encouraged in the complex span pause task during the brief 2000 ms pause. The current result can be explained by the fact that memory items in the present study were compound words and not inflected or derived words. Compound words bring a multitude of lexical factors into consideration, which include semantic transparency (whole word and constituent) (Marelli & Luzzatti, 2012) and frequency (whole word and constituent) (Blanken, 2000; Kuperman et al., 2009; Libben, 1998), relational structure which links the two constituents (Libben, 1998; Schmidtke, Kuperman, Gagné, & Spalding, 2016) and left and right constituent family size (Kuperman et al., 2009). It is apparent that the absence of rehearsal opportunity in the presence of processing demands harmed memory recall performance. This may reflect impairment of both item and position encoding as short term consolidation is interrupted by the sentence processing task. On the other hand, the opportunity to rehearse compound words in the presence of processing demands appears to aid memory recall performance. This result is supported by the TBRS model (Barrouillet et al., 2004) of WM, which argues that as the cognitive load of the processing task increases, accuracy in memory recall in the concurrent storage task declines. However, time-based decay of the compound words can be counteracted by speech-based rehearsal or attentional refreshing during allotted pauses during or between trials.

Chi-square analyses found a significantly larger proportion of omissions (participant said *blank*) in the complex span no pause task compared to both the simple and complex span pause tasks. Participants were likely overwhelmed by the combined memory and sentence reading tasks and focused more attention on the latter, unable to retrieve either of the constituents.

Participants had different error patterns in the complex span pause task compared to the simple span task. Of particular interest is the finding that nearly five times fewer one constituent errors were made in the complex span pause task compared to the simple span task. We propose that this is due to the difference in encoding strategies between the two tasks: constituents are encoded phonologically rather than semantically in the simple span task as a result of time pressure (Shulman, 1970). Therefore, retrieval depends predominantly on the phonological trace, increasing the chance of retrieving only one constituent. Rehearsal in the complex span with pause task appears to be qualitatively different because the original phonological traces are likely lost during the processing of the distractor sentences. This seems to make the constituents of a compound less likely to become activated on their own or to recombine with other words.

Of additional interest was whether serial position effects among the memory words presented in sets of four would reveal any differences between the three tasks. All three tasks showed a strong primacy and no recency effect. The significant effect of memory word position within a set is best explained by the Primacy Model (Page & Morris, 1998), which argues that in serial item recall, activation strength at encoding of successive list items decreases, forming a primacy gradient. Thus, participants recalled the first word more easily than the second word, etc. Results also showed that participants were more likely to recall a memory word correctly towards the end of the experiment.

This finding suggests that participants develop more efficient strategies during the experiment.

**Effects of lexical variables on memory recall**

By using linear mixed effects models, we were able to explore how certain lexical variables affect memory recall performance and how the mental lexicon may influence these results. Analyses revealed that a higher compound word frequency predicted a higher rate of memory recall. This finding is similar to those in eye tracking experiments (Kuperman et al., 2009) and studies employing picture naming tasks (Janssen & Caramazza, 2008). However, it contradicts Blanken (2000), who found compound constituent frequencies to have a positive effect on naming performance and not the frequency of the compound as a whole. We argue that this is a result of task demands: memory recall and sentence processing tasks invite a multitude of variables to affect performance, including short term storage (Baddeley, 1992) and retrieval demands (Taft & Forster, 1976). In the present study, factors affecting encoding and retrieval of memory items are accentuated. Compound frequency can be thought of as a factor that protects against false recombination in memory tasks. However, it may be overshadowed by constituent frequencies that support overt production in naming tasks where recombination is unlikely.

A main effect of left constituent (modifier) frequency found that a higher left constituent frequency predicted a lower overall rate of memory recall. This finding also contradicts results from Blanken (2000). All compounds in the present study were head-final. As a higher modifier frequency resulted in lower rates of memory recall, this variable and morphological family sizes of the compound words may have interacted. In the error analyses we found that a larger left family size predicted a higher rate of head error (e.g. *spaceship* instead of *spacecraft*). Results from Kuperman et al. (2009) from compound word recognition also showed a different pattern of lexical effects. They found that higher compound word frequency, left and right constituent frequencies as well as the left and right constituent family sizes facilitated performance. We propose that word forms in LTM, i.e. the mental lexicon, interact with words forms in WM during production tasks, resulting in errors that maintain the modifier and replace the head with an alternate head constituent. It can be argued that head final compounds with larger left family sizes (e.g. *snowflake*, *snowman*, *snowshoe*, etc.) and higher left constituent frequencies use the modifier as a retrieval cue at the semantic level when accessing the whole word form. A larger left family size results in greater activation of the morphological family network in the mental lexicon by the constituent morpheme, a finding compatible with Kuperman et. al (2009). This proposal is further strengthened by the fact that no significant lexical effects on modifier errors were found.

**Effects of lexical variables on recall errors according to task type**

**Simple span**

Lexical influences on errors were investigated separately for the three memory tasks. The list of compound words was strategically selected so that within each set of 4 words there was one legal recombination possible of a head and a modifier from separate words (e.g. *candlelight* + *drumstick* = *candlestick*). By including the lure pairs, we expected to see these recombination errors, confirming support for the multi-route model of lexical processing and providing information as to how words are decomposed during varying tasks of serial verbal recall. Not only did participants make such lure recombination errors, they also recombined constituents decomposed from non-lure compound word pairs. Interestingly, participants made significantly more recombination errors involving highly transparent compound words (in the highest frequency band only) in the simple span task. This is an indication that decomposition takes place in serial recall tasks that tax STM in the absence of processing demands. Highly transparent and frequent compound words were decomposed into their constituents and recombined to form both words and non-words. This can be explained as a result of competition between both constituents within the list and in the mental lexicon. Both STM and LTM activation of compound word constituents would result in greater lexical competition in simple span tasks, resulting in such recombination errors. The observation of recombination errors is compatible with results from lexical decision tasks (Sandra, 1990) using semantic primes. These found that transparent compounds (e.g. *beanpole*, *teaspoon*) were processed through morphological decomposition. No priming effects were found for semantically opaque compounds (e.g. *buttercup*, *stumbling block*).

The higher proportion of recombination errors in the simple span task supports the finding (Shulman, 1970) that at high presentation rates, it is more efficient for information to be encoded phonologically than semantically as a result of time pressure constraints. Speech-based information may be retained in the form of memory traces for two to three seconds before they fade away (or are corrupted by interference), unless refreshed by the act of rehearsal (Baddeley, 1996), which was not possible during the simple span task. As the memory words were presented at a rate of 1500 ms per word with no pause for rehearsal in the simple span task, it is possible that the two to three second lifespan of the memory traces was not sufficient for participants when it came time to recall the correct words. Alternatively, competition of the constituents with the whole compound may have resulted in forgetting.

Additional significant results concerning recall errors in the simple span task were found. Analyses revealed that a larger left family size predicted a significantly higher rate of incorrect recall of the head constituent, whereas a higher left-right similarity (how frequently two constituents appear in the same context) predicted a lower rate of incorrect recall of the head constituent. Since a high left-right similarity of two compound constituents indicates they are more likely to appear in the same context, we argue that such constituents activate one another in a given neural network and, therefore, are more likely to result in accurate recall. Recall that this is the case with a large left family size, which results in greater activation of the morphological family network in the mental lexicon by the constituent morpheme (Kuperman et. al 2009). However, this activation of the morphological family network could result in too many choices for appropriate head constituent, leading to more head constituent errors. This proposal, however, is at odds with results from a reading study (Semenza et al., 2011) with patients with left-field neglect dyslexia. The results from naming Italian words were used to argue that readers' attention is captured by the compound word's head (even on the neglected side) once implicit reading of the whole word is complete. Here, a top-down head process is proposed, making heads easier to process relative to modifiers. We explain this contradiction by arguing that reading tasks differ from memory recall during simple span tasks, which are affected by storage demands. In immediate serial recall, compound words are decomposed into their constituents and stored phonologically rather than semantically, as a result of time pressure (Shulman, 1970). During the retrieval and production process the modifier may be recombined with an incorrect head constituent.

**Complex span**

Results from the complex span no pause task analyses showed few effects of lexical variables. They revealed that significantly fewer recombination errors were made towards the end of the experiment. However, this was not found in the complex span pause condition. A learning effect would explain these findings: as the complex span no pause task progressed, participants may have developed memorization strategies that aided them in correct recall in the absence of a rehearsal opportunity. On the other hand and contrary to what has been suggested previously, opportunity for rehearsal may have harmed performance. Morphological neighbours from episodic LTM may have been activated, which compete with word forms in focused attention (Service & Maury, 2015).

Finally, none of the lexical variables explored in the study predicted the number of recombination errors in the complex span pause task. As overall recall in simple span and complex span with pause was similar, only the error analysis reveals differences between these two tasks. The pattern of results suggests that although phonological word forms may have been active at recall in both tasks, they were qualitatively different. In simple span, the phonological activation would be based on encoding all items together in a speech-based code with the help of previously stored mental lexicon representations for both the whole compounds and their constituents. All the activated representations would be able to compete with each other with recombination errors and single-constituent errors as a result. In the complex span pause task, rehearsal was encouraged. This would have required the encoding of an initial memory episode for the first target word in a set, which would lead to the retrieval of this episode at the time of encountering the second word to encode a second episode and so on until all four target words had been presented. In this case, only the two constituents of a compound word were added to the memory list at any one time while the preceding words were recalled from episodic memory and added to the rehearsal sequence. It seems that this kind of process involves less competition among simultaneously activated word forms with episodic memory providing protection against decompositional confusion.

## Conclusion

We explored how compound words are represented in STM in immediate serial recall tasks and in WM in complex span tasks that combine processing and storage demands. We were interested in exploring how different memory processes may be differentially sensitive to representation and processing aspects, as well as how recall may be affected by various lexical variables of compound words. We found that the absence of rehearsal opportunity in the presence of processing demands harms memory recall performance, which may reflect impairment of both item and position encoding as short term consolidation is interrupted by the sentence processing task. On the other hand, rehearsal opportunity in the presence of processing demands appears to aid memory recall performance. Our findings also suggest that constituents are encoded phonologically rather than semantically in simple span, as seen by the recombination errors made, as a result of time pressure. Therefore, retrieval appears to depend on the phonological trace, increasing chances of only retrieving one constituent. We also propose that word forms in the mental lexicon interact with form forms in WM during production tasks, resulting in errors that maintain the modifier and replace the head constituent. We hereby argue that head final compounds with larger left family sizes and higher left constituent frequencies use the modifier as a retrieval cue at the semantic level when accessing whole word forms.

In investigating lexical influences on errors according to task type, we found effects of lexical variables in simple span. In this task, decomposition takes place for highly transparent (operationalized as left-right similarity) compound words in the highest frequency band only. We propose that compound words with a high left-right similarity have constituents that activate one another in a neural network, resulting in complex priming and competition effects. Compound words with larger left family sizes are suggested to activate the morphological family network, resulting in too many choices for the appropriate head constituent, resulting in poorer recall. Results from the complex span no pause task analyses only showed few effects of lexical variables, apparently related to developing strategies during the experiment. Results from the complex span pause task showed no significant effects of lexical variables on recall errors. Although recall performance was similar in the simple span and complex span with pause tasks, error analyses revealed differences between the two tasks. We argue that although phonological word forms are active in both tasks, the memory constraints of the tasks differ qualitatively.

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McMaster University

Inspiring Innovation and Discovery

Date: March 17, 2015

**Memory recall for compound words during simple and complex span tasks**

Letter of Information and Declaration of Consent

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*Togo Salmon Hall 610*


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**Invitation to participate:** You are invited to participate in a study on memory recall of compound words conducted by Zoë Waelchli and Dr. Elisabet Service.

**Purpose:** This study explores individual performance in tasks that have been structured to measure memory recall performance. We are interested in your ability to recall different categories of words in two kinds of memory tasks.

**Procedure:** This study is comprised of two tasks: a simple span task and a complex span task. In the simple span task, you will be shown a series of target words in red capital letters on a computer screen. You are asked to read and remember these target words for immediate recall after list presentation. In the complex span task, you will be shown a series of sentences on a computer screen. After each sentence, a target word will be shown in red capital letters. You are asked to read these sentences and remember the target words for later recall. In addition, you will be asked a true or false comprehension question at the end of each trial. Finally, you are asked to recall the target words in the order they were presented. This experiment will take approximately one hour to complete.

**Potential harms, risks or discomforts:** It is highly unlikely that participating in this experiment will harm you in any way, though you may experience some boredom and fatigue, as the task is somewhat repetitive. The task is also deliberately difficult, so you may experience some disappointment with your performance. This should not concern you because this task is designed to be difficult for everyone. Just do your best to recall as many words in the order they were presented.

**Potential benefits:** This research will have no direct benefit to you. However, your participation will help the researchers to learn more about verbal working memory processes. This will be valuable information that the scientific community can use to understand memory processes and how word forms interact in the mental lexicon.

**Payment or Reimbursement:** If you are registered in the SONA system, you will be given course credit upon completion of the experiment. If not, you have been recruited as a volunteer. Thank you! If you

wish to withdraw from this study, you may do so at any time, without consequence. If you decide to withdraw, you will still receive your participation credit.

**Confidentiality:** Your participation in this study will be kept confidential. There will be no identifying information attached to your results. The data collected will be kept in a locked laboratory in Togo Salmon Hall and only available to the student researchers immediately involved with this study and their instructor. Collected data files with no participant information may also be used for analysis practice in future classes.

**What if I change my mind about participating in the study?** Your participation in this study is entirely voluntary. You can choose to withdraw at any time for any reason. If you decide to withdraw, you will be thanked, debriefed and compensated as if you had completed the study. Any data collected to the point of withdrawal will only be used in the analysis with your consent. Should you choose to withdraw consent to include your data in the analysis any time after completing the experiment, this will be permitted if requested **within 15 days of your participation in this experiment.** After this date, it will not be possible to remove your data from the analysis.

**Study Results:** Please leave your email address below if you wish to be informed of the results of this study when it is completed.

Email address: ___________________________________

**Information about Participating as a Study Subject:** If you have questions or require more information about the study itself, please contact the principal investigator, Zoë Waelchli at waelchzf@mcmaster.ca or the laboratory supervisor, Dr. Elisabet Service at eservic@mcmaster.ca. This study has been reviewed and cleared by the McMaster Research Ethics Board. If you have any concerns or questions about your rights as a participant or about the way the study is conducted, you may contact:

McMaster Research Ethics Board Secretariat
Telephone: (905) 525-9140 ext. 23142
c/o Office of Research Services
Email: ethicsoffice@mcmaster.ca

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CONSENT

I ____________________________ have read the information presented in the information letter about a study being conducted by Zoë Waelchli and Dr. Elisabet Service, Department of Linguistics and Languages, McMaster University. I have had the opportunity to ask questions about my involvement in this study, and to receive any additional details I wanted to know about the study. I understand that I may withdraw from the study at any time, if I choose to do so, and I agree to participate in this study. I have been given a copy of this form.

Signature: _____________________________________ Date: __________________________

Name of participant (printed): ____________________________________ SONA #:_________

Gender: ____________________ Age:_________

Signature of researcher:___________________________ Date:__________________________

McMaster University

Inspiring Innovation and Discovery

Date: March 17, 2015

**Memory recall for compound words during simple and complex span tasks**

Debriefing Sheet

*Language, Memory and Brain Laboratory*
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**1. Overview**

This study explores individual performance in a task that has been structured to measure memory recall performance, i.e. your ability to recall different categories of compound words in a given context. Some of the questions we are asking are: Is there an interaction between working memory (WM) and long term memory (LTM) for compound words of varying morphological complexity? If so, how do word forms in the mental lexicon interact with word forms in focused attention?

Working memory is a cognitive system that is responsible for the temporary storage and manipulation of information during complex cognitive tasks and has a limited amount of space to store information. Long-term memory is responsible for the storage of information over long periods of time (Baddeley & Hitch, 1974; Baddeley, 2012). This current experiment examined the interaction between working memory and long-term memory for word forms of varying morphological complexity, namely compound words. In essence, it focused on the interaction between word forms in the mental lexicon and word forms in focused attention, exploring the extent to which long term memory is involved in varying tasks of word recall.

Previous research by Service and Maury (2015) and Service and Tujulin (2002) has examined the effects of morphological complexity in Finnish on recall of word sequences in different working memory tasks. Results suggest that various word forms are all processed differently, especially when participants are allotted more or less rehearsal time, Specifically, derived words like *boy+hood* were more easily recalled when the time to rehearse them before the next sentence began was shorter whereas there was no effect of pause length before the next sentence on base words like *boy*. This indicates that representations vary based on word type and presents a challenge for theories of how meaning and form interact with cognition to allow language comprehension. Since compound words like *night train* and *morning music*

are comprised of two semantically-independent constituents, it is expected that recall errors will be made based on the semantics and morphology of the target words, sometimes leading to recombination of the two parts of a compound word, e.g. *morning train* and *night music*.

## 2. Complex Span Task

The complex span task was designed to measure memory recall performance in the presence of working memory storage and processing demands and was comprised of two kinds of trials in this study: sentence comprehension with either a short pause or a longer pause after target word presentation. Manipulating pause length affects time allotted for rehearsal of target words. In essence, a longer pause makes it possible to silently articulate, i.e. mentally rehearse, the words making up the presented list. Even a short pause allows access to long-term memory. However, a longer pause presumably allows other words related to the presented compound words to become activated in long-term memory, which can result in increased incorrect recall of target words. Errors may include words morphologically or semantically similar to the target words.

## 3. Simple Span Task

The simple span task was designed to measure working memory recall performance in the absence of a task that may limit working memory storage and processing capacity. The absence of a true or false comprehension question makes this a simple span task, as attention can be focussed solely on target word rehearsal. Simple span was comprised of one kind of trial: target word presentation with a short pause after target word presenation. Manipulating pause length is expected to affect time allotted for rehearsal of target words. Recall errors are expected to include recombinations of the activated sound presentations of the parts of compound words after a short pause.

## 4. Additional Information

Thank you very much for participating in this study. We kindly ask you to refrain from sharing the information found on this form with any potential participants in this study, as knowing the details may influence their performance and/or the results. If you have questions or concerns, please feel free to contact Zoë Waelchli by email: waelchzf@mcmaster.ca.

## 5. References

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