



Does syntax bias serial order reconstruction of verbal short-term memory?

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ABSTRACT

Existing models of short-term sequence memory can account for effects of long-term knowledge on the recall of individual items, but have rarely addressed the effects of long-term sequential constraints on recall. We examine syntactic constraints on the ordering of words in verbal short-term memory in four experiments. People were found to have better memory for sequences that more strongly conform to English syntax, and that errors in recall tended to make output sequences more syntactic (i.e., a syntactic bias). Model simulations suggest that the syntactic biasing in verbal short-term recall was more likely to be accounted for by a redintegration mechanism acting over multiple items in the sequence. The data were less well predicted by a model in which syntactic constraints operate via the chunking of sequences at encoding. The results highlight that models of short-term memory should be extended to include syntactic constraints from long-term representations—most likely via redintegration mechanisms acting over multiple items—but we also note the challenge of incorporating such constraints into most existing models.

Introduction

Short-term memory refers to our ability to temporarily store a small amount of information in order so that it may be later re-used or processed further. Although often conceived as a separate system or buffer, it is clear that verbal short-term memory is not entirely independent from long-term language representations (Baddeley, 2000; Cowan, 1999). At the level of individual items, empirical findings show that words are remembered better than non-words or unknown words (e.g., Brener, 1940; Gathercole, Frankish, Pickering, & Peaker, 1999; Hulme, Maughan, & Brown, 1991; Hulme, Roodenrys, Brown, & Mercer, 1995; Patterson, Graham, & Hodges, 1994; Saint-Aubin & Poirier, 2000); memory is better for frequently occurring words than infrequently occurring words (e.g., Gregg, Freedman, & Smith, 1989; Hulme et al., 1997; Poirier & Saint-Aubin, 1996; Roodenrys, Hulme, Alban, Ellis, & Brown, 1994; Watkins, 1977), and for frequently occurring letters compared to infrequently occurring letters (e.g., Mayzner & Shoenberg, 1964); and that highly imageable and concrete words are more memorable than those that are more abstract (e.g., Bourassa & Besner, 1994; Walker & Hulme, 1999). When considering groups of items, pairings of letters that frequently co-occur in the English language are better remembered than pairings of letters that don't frequently co-occur (e.g.,

Baddeley, 1964), even when controlling for individual letter frequency (e.g., Kantowitz, Ornstein, & Schwartz, 1972; Mayzner & Shoenberg, 1964).

Our focus here is on the contribution of syntactic constraints to order memory. Previous work has established that short-term memory is sensitive to the relationships between words in a sequence. Sequences of words that form syntactic patterns are remembered better than re-orderings of the same words that do not form syntactic patterns (e.g., Epstein, 1961; Marks & Miller, 1964), and word pairs are remembered more accurately when the order of each pair conforms to syntactic rules (e.g., itchy window) than when the order of each pair is reversed so that it doesn't match syntactic rules (e.g., window itchy; Perham, Marsh, & Jones, 2009). Long-term language representations therefore place *syntactic constraints* on the ordering of items in verbal short-term memory. Whilst this is a robust finding in the literature (e.g., Epstein, 1961; Marks & Miller, 1964; Perham et al., 2009), there is still no detailed explanation how sequence-wide relationships affect the ordering of individual items. Here we examine and test possible explanations for syntactic constraints on the ordering of words in verbal short-term memory. In particular, we show that syntactic constraints are best understood as a bias towards more syntactic word orderings, and explore how well this bias can be explained by two potential mechanisms: redintegration and chunking.

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How do syntactic constraints have an effect on verbal short-term memory?

For syntactic constraints to influence verbal short-term memory, there must be some mechanism or representation that acts over multiple items, such that recall of items is dependent on the relationship of those items to others in a sequence. This in itself presents a challenge to contemporary models of ordering in short-term memory. Many existing models represent the order of items using positional markers (e.g., Brown, Neath, & Chater, 2007; Brown, Preece, & Hulme, 2000; Burgess & Hitch, 1999, 2006; Farrell, 2012; Henson, 1998; Lewandowsky & Farrell, 2008): each item is associated with a position marker, and items are retrieved one at a time, by successively cueing for each item with its associated positional marker. Positional marking is necessary to explain grouping errors (e.g., Henson, 1999) and protrusion errors (Henson, 1998; Henson, Norris, Page, & Baddeley, 1996), whereby items mistakenly recalled in the wrong group or trial tend to retain their within-group or within-trial position. However, the serial (one-at-a-time) retrieval associated with position marking does not obviously allow for linguistic effects that act over multiple items.

To identify possible routes for the incorporation of sequence-wide constraints into popular models of serial recall, we consider here two principle mechanisms by which sequential constraints might play a role in serial recall models: *chunking* and *redintegration*. This is not to suggest that no other mechanisms are involved, but consideration of how models account for other short-term memory phenomena—particularly those related to effects of long-term memory—suggests that chunking and redintegration are the most likely candidates in providing sequential constraints on short-term recall over a broad range of contexts.

Chunking. Chunking implies the recruitment of robust, long-term representations for familiar groupings of items or events (e.g., Baddeley, 2000; Cowan, 1999; Miller, 1956). Chunks are unitized representations, with a high degree of association within chunks, and weak associations between chunks. Alternatively, chunking can be conceptualised as the compression of information on the basis of known codes (Mathy & Feldman, 2012). If short-term memory is limited to hold a certain number of chunks of information (e.g., Miller, 1956), forming several items into a single chunk means that more items can be stored in total. Although no formal description of this process has been presented, several qualitative descriptions have been offered in previous theories. Baddeley (2000) describes an episodic buffer, where information from separate short-term and long-term stores can be combined to form a single event or chunk. Cowan (1999) describes short-term memory as a highly activated portion of long-term memory, with a limited number of items activated at an above-baseline level at any one time. Items that are already strongly associated in long-term memory require less attention to co-activate than those that aren't strongly associated, leaving spare attentional resources to activate more items at an above-baseline level. A key finding addressing these theories as models of verbal chunking is that articulatory suppression does not modulate the sentence superiority effect (Baddeley, Hitch, & Allen, 2009), suggesting that the binding process involved in the formation of sentential chunks is not attentionally demanding.

The question here is how people specifically chunk on the basis of syntax so as to produce superior recall for more sentence-like sequences. One model of syntactic enhancement is that participants parse incoming word sequences according to the grammar of their native language (in this case, English). Under this model, sequences forming grammatical phrases are encoded as phrases rather than individual words. If grammar rules provide syntactic constraints on short-term memory, we might expect a verbal sequence to be chunked according to how it fits with those rules. For example, the phrase: *eats red soup the brown mole*, should be chunked into a *verb phrase* (eats red soup) and a *noun phrase* (the brown mole), according to a simple hierarchical phrase structure (e.g., Chomsky, 1965; Pinker, 1998). It is harder to predict exactly how a verbal sequence might be chunked according to frequency-of-occurrence statistics. Cowan (2001) suggested that groupings

of items within a chunk would be more strongly associated to each other (possibly due to frequency of co-occurrence) than groupings across chunk boundaries, but it is difficult to specify exactly what thresholds of association qualify items for inclusion in or exclusion from a chunk. For this reason, the current study only aims to test the hypothesis that verbal sequences are chunked according to grammar rules.

Previous work has noted the possibility that grammatical structures are chunked in memory. Gilchrist, Cowan, and Naveh-Benjamin (2008) found that recall of word sequences was limited by the number of clauses those sequences contained. In addition, they found that older adults showed a reduced tendency to access new clauses, but having accessed a clause were as likely to complete the clause as younger adults. Gilchrist et al. (2008)'s tentative interpretation was that words in the same clause form part of a single chunk in working memory, and thus present similar constraints as other types of chunks such as pre-learned word pairs (Naveh-Benjamin, Cowan, Kilb, & Chen, 2007). The dynamics of recall are also consistent with chunking of grammatical structures, with longer latencies to the first item in each constituent syntactic chunk (e.g., Martin, 1967; Wilkes & Kennedy, 1969).

There is a subtle distinction to be made here between chunking and grouping, although both can have similar effects on response latencies. Grouping involves the hierarchical organisation of items in a sequence according to perceptual qualities of the sequence at presentation. For example, sequences can be separated into groups by inserting temporal pauses between groups (e.g., McLean & Gregg, 1967; Parmentier & Maybery, 2008), presenting items in different voices or from different spatial locations (e.g., Parmentier & Maybery, 2008), or spontaneously by the participant (e.g., Farrell & Lelièvre, 2009; Madigan, 1980). Response latencies to the first item in each group tend to be longer than for the other items in the group (e.g., Farrell & Lewandowsky, 2004; Maybery, Parmentier, & Jones, 2002; McLean & Gregg, 1967; Parmentier & Maybery, 2008). Chunking is a similar form of hierarchical organisation of items in a sequence, but based on unitized representations for each chunk (Johnson, 1970). For example, if a particular sub-sequence of items is very familiar, it could form a chunk in short-term memory (Baddeley, 2000).

Two testable predictions follow from a syntactic chunking mechanism. The first is that chunking according to the syntactic structure of the presented sequence at encoding should lead to improved recall for sequences that match the syntactic constraints in long-term memory, as they would form fewer chunks to be remembered. The second prediction is that latencies to the first item in each syntactic chunk should be longer than latencies to later items in each syntactic chunk. Previous work has found that people leave pauses between chunks in their recall (e.g., Ericsson, Chase, & Faloan, 1980), and chunking models of working memory assume a time cost to accessing new chunks that is borne out empirically (e.g., Anderson & Matessa, 1997; Daily, Lovett, & Reder, 2001; Johnson, 1972).

Redintegration. Redintegration is a process of reconstruction of degraded short-term memories using long-term knowledge (e.g., Brown & Hulme, 1995; Lewandowsky & Farrell, 2000; Schweickert, 1993). When the degraded short-term memory for a sequence is ambiguous (i.e., it could match several possible sequences), the reconstruction that is most likely to be recalled is the sequence (out of those credible options) that best matches the sequential constraints represented in long-term memory.

Redintegration has traditionally been applied to the reconstruction of individual items on a list to be remembered (e.g., Lewandowsky & Farrell, 2000; Schweickert, 1993). Nonetheless, Schweickert (1993) noted that redintegration may take place over a whole list of items, even though he only applied it to individual items. There are two areas of evidence that suggest redintegration does occur over multiple items in a list: The composition of the whole list seems to influence accuracy of recall of individual items; and ordering within the list appears to be regularised.

The majority of evidence for whole-list composition influencing

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