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Questioning short-term memory and its measurement: Why digit span measures long-term associative learning

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ABSTRACT

Traditional accounts of verbal short-term memory explain differences in performance for different types of verbal material by reference to inherent characteristics of the verbal items making up memory sequences. The role of previous experience with sequences of different types is ostensibly controlled for either by deliberate exclusion or by presenting multiple trials constructed from different random permutations. We cast doubt on this general approach in a detailed analysis of the basis for the robust finding that short-term memory for digit sequences is superior to that for other sequences of verbal material. Specifically, we show across four experiments that this advantage is not due to inherent characteristics of digits as verbal items, nor are individual digits within sequences better remembered than other types of individual verbal items. Rather, the advantage for digit sequences stems from the increased frequency, compared to other verbal material, with which digits appear in random sequences in natural language, and furthermore, relatively frequent digit sequences support better short-term serial recall than less frequent ones. We also provide corpus-based computational support for the argument that performance in a short-term memory setting is a function of basic associative learning processes operating on the linguistic experience of the rememberer. The experimental and computational results raise questions not only about the role played by measurement of digit span in cognition generally, but also about the way in which long-term memory processes impact on short-term memory functioning.

1. Introduction

A short-term, limited capacity system for the temporary maintenance and manipulation of information has formed an integral component of cognitive architectures since the foundations of cognitive science. It is typically construed as a mode of processing separate from, but interactive with long-term memory and the particular form this relationship takes has been theorized, broadly, in two ways; short-term memory (STM) is either seen as a set of processes and representations discrete from long-term memory, with the interaction involving both formation of new long-term memory representations and support from existing ones (e.g., Baddeley, Gathercole, & Papagno, 1998; Hulme et al., 1997; Page & Norris, 2009) or STM is that aspect of long-term memory that is currently activated by some sort of limited-capacity attentional process (e.g., Cowan, 1995; MacDonald & Christiansen, 2002; Martin & Saffran, 1997).

For both of these broad approaches, a key focus is on the influence of long-term linguistic knowledge on performance in verbal STM tasks. In general terms, STM for verbal material that corresponds to the rememberer's linguistic knowledge is better than that for material that deviates from it: serial recall for sequences of words is better than that for nonwords (Hulme, Maughan, & Brown, 1991) and recall of sequences of high frequency words is better than that for sequences of low frequency words (Hulme et al., 1997); sequences of nonwords constructed to conform to the phonotactic regularities of the rememberer's own language sustain better serial recall than those that do not (Majerus, van der Linden, Mulder, Meulemans, & Peters, 2004); sequences of words in the rememberer's first language are recalled better than those from the second language (Messer, Leseman, Boom, & Mayo, 2010), and so on.

The two approaches also share a general explanatory orientation in that they both attribute (albeit in different ways) the advantage for linguistically familiar material to enhanced integrity of the

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items that form the memory sequences. For those accounts of STM that regard it as a mode of representation discrete from long-term memory, a process of redintegration is argued to take place (at encoding, storage or retrieval) such that long-term lexico-phonological representations may be used to counteract the effects of decay and/or interference that have degraded the corresponding volatile representations in short-term storage (e.g., Hulme et al., 1997; Schweickert, 1993). Those accounts that view STM as the currently activated portion of long-term memory attribute the superior performance for linguistically familiar phonological material to additional, sustained activation that accrues from the mutual connections that exist between the lexical and semantic features of words and their phonological features, as well as the increased integrity – due to frequent co-activation – of the phonological features of familiar words compared to novel or infrequent ones (e.g., Jefferies, Frankish, & Noble, 2009).

However, the influence of long-term linguistic knowledge has also been shown to operate on sequence-level factors that transcend the particular characteristics of the individual items making up those sequences. For example, sequences of alternating pairs of adjectives and nouns are better remembered if the adjective–noun ordering corresponds to that found in the rememberer's language (Acheson & MacDonald, 2009; Perham, Marsh, & Jones, 2009). Also, sequences within which the coarticulatory transitions between successive items are relatively fluent sustain better serial recall than sequences containing more complex or unfamiliar transitions, even when the items making up those sequences are equivalently familiar (Murray & Jones, 2002; Woodward, Macken, & Jones, 2008). The influence of such sequence level factors is not typically integrated into models of STM (Burgess & Hitch, 1999; Henson, 1998; Nairne, 1990; Page & Norris, 1998), within which the ordering of successive items is accomplished by some sort of order or positional cue (e.g., a primacy gradient or an oscillating context signal) which is implemented separately from the items making up the sequence.

An exception to this picture relates to the influence of pre-test exposure to particular sequential regularities of material that is subsequently subjected to serial recall or the repetition within an experimental block of particular orders of items (e.g., Burgess & Hitch, 2006; Hebb, 1961; Majerus, Martinez Perez, & Oberauer, 2012). The focus in such settings has typically been on the transmission of information from short-term processing to long-term memory – for example, with respect to the learning of new multisyllabic words (e.g., Baddeley et al., 1998; Page & Norris, 2009). The effect of recent exposure to novel transitional regularities on the subsequent serial recall of sequences corresponding to such regularities raises the question of the impact of long-term sequence learning within the short-term setting (e.g., Botvinick & Bylsma, 2005; Majerus et al., 2012). However, conceptual orientations that propose bespoke short-term memory processes distinct from other learning mechanisms seek to ensure that such factors are nullified within STM methodologies by deliberately excluding sequences which might correspond to the linguistic repertoire of the rememberer (e.g., common acronyms, canonical runs of letters or digits). In such a way, the study of STM appears to immunize itself from certain aspects of long-term linguistic knowledge (i.e., those that pertain to the level above the ostensible item), while embracing the influence of others (those that pertain to the item). In particular, it methodologically seeks to immunize itself from potential influences of what we would conceive of as long-term associative influences (other than those obtained within the experimental setting, such as the Hebb effect), which is to say that in a setting that examines rememberers' ability to retain and manipulate sequences of verbal information, the question of whether or not those sequences (as opposed to the items they are drawn from) are familiar is excluded from the analysis.

Along with the generative linguistics with which it shares conceptual and historical origins, contemporary theorizing about verbal STM, therefore, posits a fundamental distinction between the processes whereby a set of verbal information may be instantiated sequentially, and the actual elements that make up the content of that sequence. In this way, the typical short-term serial recall task is conceived of a setting in which the rememberer must deal with a novel verbal event by applying an item-independent ordering process to a set of *a priori* items. Here we propose a different way of construing the task setting, and concomitantly, a different way of construing STM. In particular, we propose that the way in which novelty is dealt with in instance- or exemplar-based theories of language may be applied also to the typical STM setting. Such approaches (e.g., Bybee, 2010; Goldberg, 2003; Pierrehumbert, 2003; Tomasello, 2005) account for novel verbal behaviour, broadly, in terms of analogy, rather than a generative approach that involves the application of a general ordering rule or process to a novel set of items. So, the readiness with which novel verbal events may be processed is related not only to the individual items involved but also to the extent to which similar events that may serve as analogies may be retrieved and applied from the participant's previous long-term linguistic experience. Such exemplar-based approaches to language have been shown to provide more ready and parsimonious explanations for an increasingly wide range of linguistic phenomena that are not well accounted for by more traditional structural or generative accounts of language (see e.g., Beckner et al., 2009 for an overview).

On the face of it, it might appear that the STM setting is immune from such an analysis, given the typical approach, discussed above, of deliberately excluding sequences likely to have been encountered previously by the participant. However, the question of prior encounters with a particular sequence (or part thereof) presented to a participant in a STM experiment is not simply a matter of familiarity versus novelty; rather, it will always be a matter of degree. Indeed, the influence of the type of sequence level linguistic characteristics discussed above (e.g., syntactic and phonotactic regularity) could be construed as just such an influence on short-term serial recall, via a process of analogy, of the degree of similarity between the given sequence and the content of the participant's natural linguistic experience (e.g., Goldberg, 2003). Here we provide a detailed analysis of another robust effect in STM – superior recall for sequences of digits over sequences of other types of items – which, we argue, speaks to just this issue. At first glance, such an effect might appear readily amenable to the typical item-oriented account – for example, perhaps digits have some inherent characteristics that make them easier to remember than other items. However, it turns out instead to provide proof of principle for the overlooked influence of long-term associative factors on STM performance, even in those settings in which such factors have been ostensibly eliminated. This analysis has implications, therefore, not only for how digit span performance is to be interpreted, but also for how STM itself is to be theorized; and in particular, since the assessment of STM plays a key role in many accounts of other, higher cognitive functions, for how its role in those functions is to be construed.

Digit span is the standard test of verbal STM performance that is routinely used in psychological studies, either as a stand-alone test or as part of a number of psychological assessment batteries (e.g., Elliot & Smith, 2011; Kaufman & Kaufman, 2004; Wechsler, 2008, 2009). The task involves progressively longer sequences of digits being presented, the goal being to recall them in their correct order until two sequences of a particular length are recalled incorrectly. Span is usually taken to be the number of sequences accurately