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# Effects of rhythm on memory for spoken sequences: A model and tests of its stimulus-driven mechanism



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### ABSTRACT

Immediate memory for spoken sequences depends on their rhythm – different levels of accuracy and patterns of error are seen according to the way in which items are spaced in time. Current models address these phenomena only partially or not at all. We investigate the idea that temporal grouping effects are an emergent property of a general serial ordering mechanism based on a population of oscillators locally-sensitive to amplitude modulations on different temporal scales. Two experiments show that the effects of temporal grouping are independent of the predictability of the grouping pattern, consistent with this model's stimulus-driven mechanism and inconsistent with alternative accounts in terms of top-down processes. The second experiment reports detailed and systematic differences in the recall of irregularly grouped sequences that are broadly consistent with predictions of the new model. We suggest that the bottom-up multi-scale population oscillator (or BUMP) mechanism is a useful starting point for a general account of serial order in language processing more widely.

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## 1. Introduction

Language is inherently serial, and the representation and control of serial order are fundamental considerations for any model addressing linguistic processes or the interactions of memory and language. Over half a century ago, [Lashley \(1951\)](#) recognized that the capacity for serial behaviour had to be reconciled with evidence of parallel processing in the brain, and suggested that rhythmic patterns of neural activity could play a mediating role. Since then theoretical approaches to serial order within the language domain have tended to diverge, with a proliferation of models for speech production (e.g., [Dell, Burger, & Svec, 1997](#); [MacKay, 1970](#); [Vousden, Brown, & Harley, 2000](#)), verbal short-term memory (e.g., [Botvinick & Plaut, 2006](#); [Brown, Preece, & Hulme, 2000](#); [Burgess & Hitch, 1999](#); [Henson, 1998](#); [Lewandowsky & Farrell, 2008](#); [Page & Norris, 1998](#)), and speech perception (e.g., [Grossberg, 2003](#)). In each area models have incorporated many of [Lashley's \(1951\)](#) insights, but typically not that of the central and potentially unifying importance of rhythm.

In the present paper, we focus on effects of rhythm and timing in auditory-verbal short-term memory. Recall of rhythmically grouped sequences is typically much better than ungrouped sequences, and the improvement is associated with characteristic changes in patterns of order errors ([Ryan, 1969a, 1969b](#)). These phenomena place constraints on theories of serial order in short-term memory and these in turn have implications for developing an understanding of the broader problem of serial order in language more generally. We replicate and extend the work of [Ryan \(1969a\)](#) showing grouping effects for irregular and unpredictable patterns of temporal grouping which, we argue, are inconsistent with explanations of grouping in terms of strategic processes such as rehearsal ([Broadbent, 1975](#); [Chi, 1976](#); [Lewandowsky & Brown, 2005](#); [Parmentier & Maybery, 2008](#); [Wickelgren, 1964, 1967](#)), and beyond the scope of current computational models of serial order in short-term memory. Using insights from such models, we propose a new mechanism in which serial order is encoded by a population of oscillators driven bottom-up by auditory-verbal input and sensitive to local variation in its temporal structure. Through simulations we demonstrate that many subtle and detailed features of the empirical data on short-term memory for grouped sequences can be understood as emergent properties of this general mechanism. We conclude by discussing the potential of the bottom-up multi-scale population oscillator (or BUMP) mechanism as a starting point for a more general theory of serial order in language processing, potentially linking speech perception, speech production and verbal short-term memory through their common dependence on rhythm and timing.

### 1.1. Verbal short-term memory: structure, function and mechanisms

Although it might initially appear an esoteric skill, the capacity to retain ordered spoken material over a brief interval is fundamental for many aspects of language processing. Thus, many authors view verbal short-term memory as a property of the language processing system (e.g., [Allen & Hulme, 2006](#); [Martin & Saffran, 1997](#); [Monsell, 1987](#)), and the capacity for immediate verbal recall has been shown to play a key role in the acquisition of vocabulary and language development ([Baddeley, Gathercole, & Papagno, 1998](#)). The mechanisms underpinning verbal short-term memory have principally been studied in tasks involving the immediate serial recall of sequences of items such as digits, letters or words. There is substantial evidence from performance in such tasks that the underlying system is speech-based. Thus, recall is disrupted when items sound alike ([Conrad, 1964](#)) or take longer to say ([Baddeley, Thomson, & Buchanan, 1975](#)) or when the memory task is accompanied by irrelevant spoken output ([Murray, 1967](#)). These effects of phonological similarity, word length and articulatory suppression, respectively, fall into a systematic pattern that has been widely interpreted as reflecting the operation of a store containing transient phonological memory traces that can be refreshed by subvocal rehearsal ([Baddeley & Hitch, 1974](#); see also [Baddeley, 1986, 2007](#)). Despite its critics (e.g., [Jones, Hughes, & Macken, 2007](#)), this account of verbal short-term memory as a “phonological loop” has been highly influential. However, in its original form it offered no explanation of memory for serial order and did not address key phenomena such as the shape of serial position curves, the distribution of order errors, and effects of temporally grouping items during sequence presentation. The following

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