Verbal Short-Term Memory and Language Processing: A Computational Model

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According to the *working memory model* (Baddeley, 1986), human verbal short-term memory performance, as studied in immediate serial recall (ISR) tasks, depends on the *articulatory loop*, which consists of a *phonological store* for verbal material, and mechanisms that enable *rehearsal*. The articulatory loop model provides a simple and elegant account of a wide range of phenomena observed in ISR tasks. Despite its impressive contributions, however, there is increasing evidence to suggest that the account it offers is too simplistic. One area of deficiency is that the articulatory loop model offers no account of the ubiquitous primacy and recency effects observed in serial recall of lists. Second, the model implicitly assumes that rehearsal is necessary for performance of ISR. Consequently, it cannot account for the existence of serial recall without rehearsal, evidenced in children (Gathercole, Adams, & Hitch, 1994) and in neuropsychologically impaired patients (Howard & Franklin, 1990). Third, the model provides no account of the effects of long-term lexical knowledge on serial recall (Hulme, Maughan, & Brown, 1991). Fourth, the articulatory loop framework highlights but does not provide a detailed account of the relationship of ISR to vocabulary ability and nonword repetition abilities (Gathercole et al., 1994).

We have developed a computational model that attempts to integrate these phenomena into an account of ISR that also relates the mechanisms to those of language processing more generally. The model builds on many previous ideas (e.g., Hartley & Houghton, in press), and is depicted in Figure 1. There are three crucial levels of representation: the Phoneme Layer, a level of output phonology at which phonemes are represented; the Phonological Chunk Layer, at which word forms are represented for both input and output phonology; and the Semantics/Context Layer, at which semantic and/or contextual information about word forms is represented. These levels of representation are related via connection weights as shown in Figure 1. Production of a word form is a serially ordered process, therefore the representation of a word form at the Phonological Chunk Layer has to be able to produce a specific sequence of phonemes at the Phoneme Layer.

There is a general sequencing mechanism (designated as the Sequence Memory) that provides immediate memory for sequences of word forms, i.e., that can replay a sequence of activations that have occurred recently at the Phonological Chunk Layer. The connection weights from the Sequence Memory are subject to decay, and therefore the memory for specific sequences is short-lived.

The model was used to simulate three abilities: (1) immediate repetition of novel word forms, (2) the learning of novel word forms, and (3) immediate serial recall of lists of known word forms. Simulated immediate repetition performance was 100% correct, corresponding to essentially error-free performance in normal adult human subjects. In simulations of word learning, all the words were learned on the first presentation, corresponding to human subjects' abilities to learn words within a very few presentations. In simulated ISR of lists of 1 to 7 word forms, the model's performance was perfect for list lengths 1 through 4, and dropped off with increasing list length, showing a good correspondence with the human data. Moreover, for list lengths 5 through 7, the distribution of errors exhibited characteristic primacy and recency effects.

Thus the model's performance of immediate serial recall (ISR), nonword repetition (NWR), and word learning (WL) is in agreement with human behavioral data. To understand the relationship between these abilities, note that the model's performance depends on the effectiveness of the mappings between its various components. The Phonological Chunk Layer $\rightarrow$ Phoneme Layer mapping represents long-term phonological knowledge (knowledge about the serial order of phonemes within words). The Semantics/Context Layer $\leftrightarrow$ Chunk Layer mapping represents long-term semantic knowledge. The Sequence Memory $\rightarrow$ Chunk Layer mapping represents the inherent capacity of the *short-term* Sequence Memory.

To examine how NWR, WL, and ISR depend on these three mappings, the model's performance was analyzed when the effectiveness of each mapping was varied (by varying the strength of its connection weights), while keeping the effectiveness of the other two mappings constant. Simulation results were as follows. (1) ISR ability depends on the effectiveness of long-term phonological knowledge, long-term semantic knowledge, and short-term sequence memory capacity. (2) Word learning ability depends on the strength of long-term phonological knowledge and long-term semantic knowledge. (3) Nonword repetition ability depends on the strength of long-term phonological knowledge. These results suggest a more precise specification of the relationship between serial recall and word learning. Both abilities depend on the Chunk $\rightarrow$ Phoneme mapping and the Semantics/Context $\leftrightarrow$ Chunk mapping. These mappings represent fundamental aspects of phonological/linguistic processing and long-term knowledge.

The model thus suggests answers to issues that the articulatory loop framework does not address. First, there is no rehearsal mechanism in the present model, which therefore accounts for ISR without rehearsal. Second, the model accounts for serial position effects. Third, the model indicates how long-term lexical knowledge plays an important role in ISR. Fourth, the model accounts for the relationship between ISR and vocabulary ability. More generally, the present model specifies a relationship between the domains of verbal short-term memory and language processing, suggesting that the former is importantly dependent on core mechanisms subserving the latter.

STM deficits have received considerable attention in neuropsychology, and there is growing interest in their relation to linguistic deficits. The present computational results suggest one possible basis for such a relationship. Attempting to apply this framework to understanding patterns of neurological deficit is an important aim of future investigation.

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Figure Caption

Figure 1. A computational model of word learning, nonword repetition, and immediate serial recall.

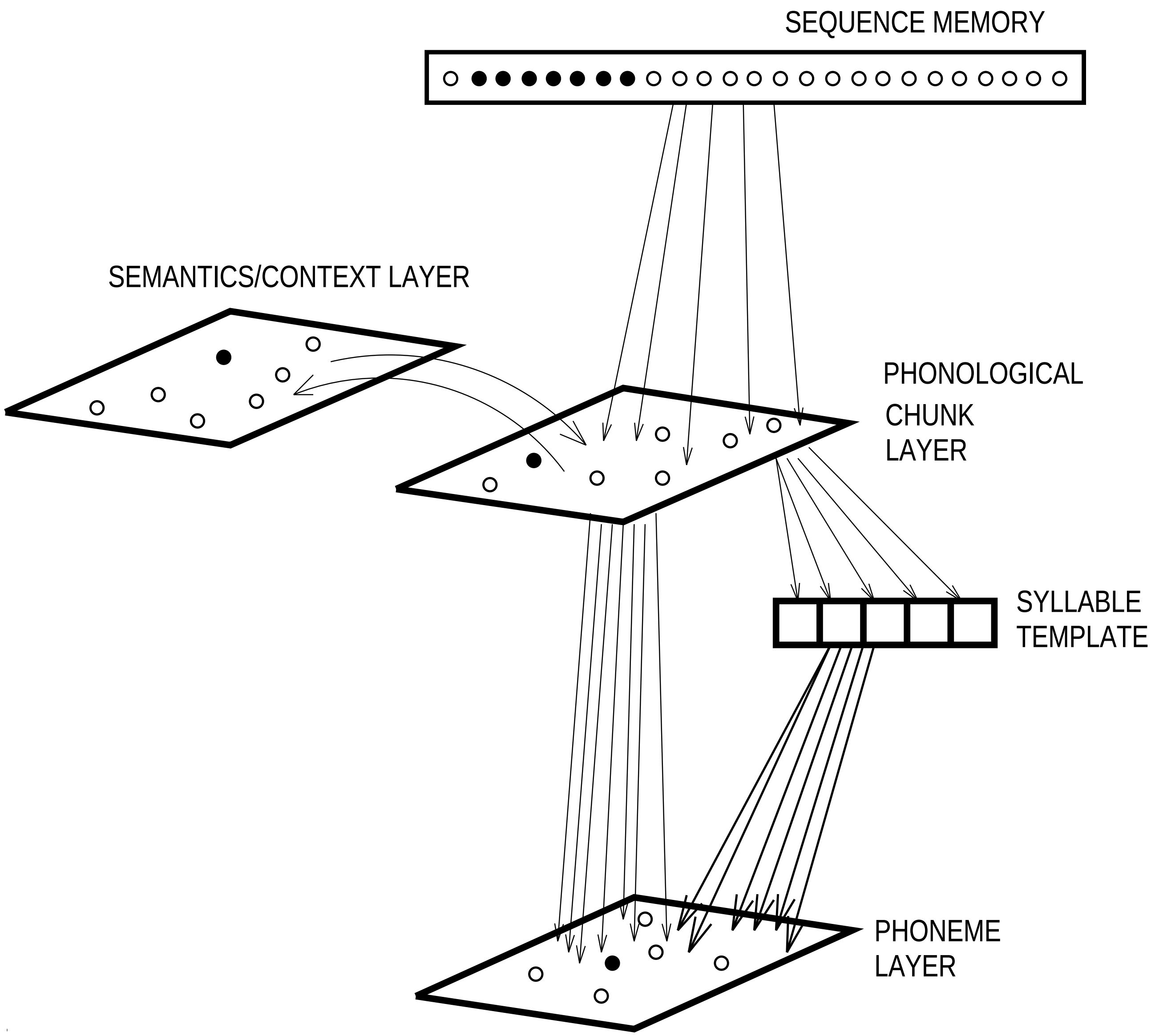
SEQUENCE MEMORY
SEMANTICS/CONTEXT LAYER
PHONOLOGICAL
CHUNK
LAYER
SYLLABLE
TEMPLATE
PHONEME
LAYER

Figure 1: