Are position effects in the reproduction of letters from words the result of serial binding?

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Although some models of visual-word processing are serial in nature (1, 2), none of them contains binding as a central element in bottom-up and top-down processes. In bottom-up processes, binding is necessary to account for location- and position-invariant representation of letters. In top-down processes binding is needed to generate a response to questions requiring the combination of a letter's identity with its location or position, for example when the position of the n-th letter of a word or non-word is asked for. This latter question is referred to as the letter-reproduction task.

In Figure 1 a general parallel, neural architecture is described in the form of a conceptual network (3-5). In this architecture the processing of a word (e.g. the word ‘BAT’) is represented as the rapid, serial binding of the identity, location, and position of letters. In the network letters and words are nodes and node structures. Each node is a cell-assemble based on the Tanzi-Hebb learning rule. Consequently each node represents a memory trace that must have a critical threshold. When the activation level of a cell-assembly remains below the critical threshold, at the functional level the corresponding memory trace is in a state of priming. When its activation level exceeds the critical threshold, this corresponds to a memory trace in working memory in traditional functional models. In the network excitation loops come into existence and propagate selectively through the network. The conceptual network contains a spatial map for the representation of the location of objects.

Two unconnected memory traces can enter a state of temporary resonance. This temporary binding occurs if 1. both are simultaneously active, 2. both memory traces are also activated from the subnetwork representing their context.

On the presentation of a word, temporary bindings (dashed lines in Fig. 2) occur between the memory traces of the letter word, the spatial map, and a General Sequence Network (GSN). When a non-word is briefly presented, the memory traces for the letters become weakly activated. As a consequence of activation decay, the serial binding of letter nodes to the position nodes in the GSN will deteriorate for the letters on the higher positions. To a lesser extent this deterioration applies to the binding of the node for the last letter. The propagation of excitation loops then reaches the end of the GSN and a reverberation is assumed to occur that enhances the strength of the binding of the last-letter node to the GSN. When a word is presented, the sequence networks specific to each word node generate position-specific top-down activation during the binding process. This increases the activation level of the letter nodes involved, therefore a stronger binding with the GSN is established. The bindings between the GSN and the letter nodes are assumed to be re-entrant. After they have come into existence with the presentation of a (non-)word, they are re-activated when the network has to give the response in a letter-reproduction task.

The accuracy in the reproduction of a letter from a briefly presented word or non-word is dependent on the strength of the temporary binding involved. The accuracy for words will therefore be higher than for non-words and for both decrease with letter position, with an exception for the last letter. The letter reproduction tasks of Exps 1, 2, and 3 (Figure 2) were designed to test this hypothesis with four-, five-, and six-letter words.

Figure 3 shows that the experimental data are largely consistent with the data generated by a simulation of a simplified version of a conceptual network, given suitable parameter values. The outcomes of the simulations, indicated by the triangles in Figure 3, closely match the bars of the experimental results. The enhanced accuracy for the third position in a five-letter non-word is accounted for by the point of fixation of the eye.

In order to test the hypotheses on binding, the simultaneous activation of letter nodes as well as their context was manipulated. In Exp. 4 the five-letter (non)words were either embedded by simultaneously presented letters or by non-alphanumeric symbols (see Fig. 2). The results in Fig. 4 show that in the embedding-letter condition the accuracy on positions 1 and 2 as well as on position 5 decrease because of the changed context. According to the model the memory traces of embedding letters may then intrude into the context of the task, and in some cases become erroneously bound to the GSN. This explains the observed decrease in accuracy. Since the embedding symbols are semantically distinct from the embedding letters, they do not intrude into the task context. In the embedding-symbol condition (Fig. 4) the observed accuracies therefore largely comply with the model simulations for Exp. 2, in which there were no context manipulations.

In Exp. 5 the same context manipulation was carried out as in Exp. 4 but the embedding letters and symbols preceded the presentation of the five-letter (non)words. Within the model this means that the simultaneity of activation of the memory traces of the embedding letters with memory traces of letters in the presented (non)word is less strong. As a result the number of erroneous bindings is reduced. Accordingly, in Exp. 5 the embedding-letter and -symbol condition comply to a large extent with the model simulations for Exp. 2 (Fig. 4).

References