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Testing sequence effects in visual memory: clues for a structural model

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Abstract

In order to probe the internal organization of visual temporary memory, systematic experiments were performed in which the subjects had to memorize a series of 2–5 images then pass recognition tests, either in all possible testing permutations, (in the case of 2–4 images) or in 20 selected permutations (in the case of 5 images). Over 300,000 tests were performed, generating more than 40,000 errors. The error-rates were found to follow simple rules. Both the 3 and the 4 images results are compatible with the presence of only four typical accuracy levels. On the other hand, the reaction time (RT) results revealed surprisingly rich patterns. The RT for recognizing image i at testing stage $t > 1$ depends upon which image (j) was tested just before. The ranking of the RTs for (j, i) couples evolves from one testing stage to the next. It is proposed that these RTs reflect, in part, the time needed to localize the trace in memory of a given image, starting from the position at which the previous test occurred. If this assumption is correct, the results of this study are providing a picture of the configurations formed by memorized items in the visual temporary store. A hypothetical minimal model, involving several rows of slots on a triangular mesh is proposed to account for the structures in both the error-rates and the RT results.

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1. Introduction

The concept of a short-term limited memory span was already familiar at the end of the 19th century (review in Murray, 1976). When subjects are asked to memorize a small set of N items, presented at intervals of 1 or 2 s, then asked to recall the whole set, the recall is practically error-free for N inferior or equal to a value S —typically, 7 for digits, and 3 or 4 for images. For many decades, the memory span S was thought to be the number of slots of a temporary memory store. More than S items may be acquired, by chunking two or more items into a single, more complex one. S also clearly depends upon the dynamics of acquisition and recall (see, e.g., Cavanagh, 1972). So, S might be reinterpreted as reflecting a “dynamic bottleneck”—the kind of traffic jam which arises when cars are running too fast. There is also a substantial body of theoretical work on “distributed memory models”, which predicts limited storage capacities, but with no identifiable slots (cf. Amit & Mongillo, 2003; Fuster, 1997).

Intuitively, in “old-fashioned” models with slots, each memorized item can be treated as a separate entity, and tracked as the testings proceed. In more modern distributed memory models, the stored information may be degraded with time, but the memorized items behave cohesively. This is why we will pay attention to fine structural details in the data, looking for features, if they exist, which differentiate the memorized items.

Within a set of N memorized items, not all the items are recognized with the same ease. In verbal memory, recall accuracy is described by a U-shaped curve. Both the first and the last items are better recalled than the intermediate ones (this is the widely discussed theme of serial position, primacy, and recency effects, see e.g., Crowder, 1976; or, more recently, Knoedler, Hellwig, & Neath, 1999). In contrast, there is a simpler phenomenology in visual memory. Phillips and Christie (1976) found, to the precision of their experiments, that all but the last item, in sets of $N = 3–8$ items are equally well recognized. At a finer level of analysis, the function relating recognition accuracy to the number N of memorized items has, in the case of visual memory a (subject-dependent) stepwise character. We found a first decline of recognition accuracy for two out of three subjects after $N = 3$, and another decline for all subjects after $N = 9–12$ (Ninio, 1998). In subsequent unpublished work with three more subjects plus the author, the first decline was after $N = 4$ or 5, and the second was at $N = 10–12$. Furthermore, by reducing the difficulty of the tests, one can reach a close to zero error-rate on 5 or 6 images.

There is a contradiction with the accepted memory span of 3 or 4 for images (e.g., Cavanagh, 1972; Cowan, 2001) which, is however, only apparent. On one side, the memory span is obtained as a cutoff value separating perfect from imperfect recall under strictly defined dynamic conditions, and on the other side, the results of Phillips and Christie (1976), as well as ours, are obtained under less constraining conditions. To make this point more concrete, assume that you have memorized $S = 4$ items into the 4 slots of a temporary memory store and now try to memorize one more item. Assume that the acquisition of this item is compensated by the loss, at random, of one of the 4 previously stored items. So, we do have a store with 4 slots,

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