Journal of Memory and Language 97 (2017) 81–102

Contents lists available at ScienceDirect

Journal of Memory and Language

journal homepage: www.elsevier.com/locate/jml

Order of items within associations ☆

Kenichi Kato, Jeremy B. Caplan *

Department of Psychology, University of Alberta, Canada

ARTICLE INFO

Article history:
Received 16 January 2017
Revision received 6 June 2017

Keywords:
Associations
Order
Cued recall
Associative recognition
Mathematical models
Verbal memory

ABSTRACT

Association-memory is a major focus of verbal memory research. However, experimental paradigms have only occasionally tested memory for the order of the constituent items (AB versus BA). Published models of association-memory, implicitly, make clear assumptions about whether associations are learned without order (e.g., convolution-based models) or with unambiguous order (e.g., matrix models). Seeking empirical data to test these assumptions, participants studied lists of word-pairs, and were tested with cued recall, associative recognition and constituent-order recognition. Order-recognition was well above chance, challenging strict convolution-based models, but only moderately coupled with association-memory. Convolution models are thus insufficient, needing an additional mechanism to infer constituent order, in a manner that is moderately correlated with association-memory. Current matrix models provide order, but over-predict the coupling of order- and association-memory. In a simulation, when we allowed for order to be wrongly encoded for some proportion of pairs, order-recognition could be decoupled from cued recall. This led to the prediction that participants should persist with their incorrect order judgement between initial and final order-recognition, but this was not supported by the data. These findings demand that current models be amended, to provide order-memory, while explaining how order can be ambiguous even when the association, itself, is remembered.

Introduction

Association-memory has been a major focus of empirical and mathematical modelling studies of verbal memory, but has generally been studied separately from another topic considered important for behavior, memory for order (e.g., Kahana, 2012; Lashley, 1951; Murdock, 1974; Neath & Surprenant, 2003). An important question, then, is whether associations are remembered with or without order. That is, after studying a pair such as croissant–coffee, can the participant determine that the studied pair was croissant–coffee, not coffee–croissant? The dominant behavioral paradigms used to quantify association-memory do not test memory for the order of the constituent items: In cued recall, one item is given as a cue and the other is requested as the response. To answer croissant ? ("forward" cue), the participant need only remember that croissant and coffee were paired together; if the wrong constituent-order is retrieved, the participant is at no disadvantage. Likewise, given the cued-recall probe coffee ? ("backward" cue), the participant still need only remember the pairing; constituent-order is irrelevant. Associative recognition, also used to test association-memory, typically includes "intact" probes, such as croissant–coffee, along with "rearranged" probes. If a second studied pair were apple–soup, the probe croissant–soup would be an example of a rearranged pair. Constituent-order is not explicitly tested with these two probe types because items remain in their original positions in both rearranged and intact probes.

This is a problem for the development of models of association-memory. As Rehani and Caplan (2011) noted, published models always need to adopt an assumption about how constituent-order is stored (or not stored), even though the authors of those models did not intend to make any predictions about memory for constituent-order. We dig deeper into existing models in the General Discussion, but here we illustrate the problem, contrasting two major mathematical operations that are at the heart of a large number of vector-models of association-memory: convolution and matrix outer-product. First, we note that we know of no published implementation of order-recognition in a model of association-memory. However, existing models do present obvious ways one might implement order-recognition.

In convolution-based models (Longuet-Higgins, 1968; Metcalfe Eich, 1982; Murdock, 1982; Plate, 1995), two item-vectors, **a** and **b** (column-vectors are depicted in boldface), are convolved together,

☆ The authors thank Michael Dawson, Clayton Dickson, Yang Liu and Tomi Ann Limcangco for helpful feedback on the manuscript. Supported by the Natural Sciences and Engineering Research Council of Canada.

* Corresponding author at: Department of Psychology, Biological Sciences Building, University of Alberta, Edmonton, Alberta T6G 2E9, Canada.

E-mail address: jcaplan@ualberta.ca (J.B. Caplan).

http://dx.doi.org/10.1016/j.jml.2017.07.001
0749-596X/

denoted $\mathbf{a} \circledast \mathbf{b}$, before being added to a memory vector, $\mathbf{w}$. Because convolution, $\circledast$, is commutative, $\mathbf{a} \circledast \mathbf{b} = \mathbf{b} \circledast \mathbf{a}$. This means that after the association is stored, the model has no way to differentiate whether the pair was AB or BA. A model that stores associations only with convolution would, therefore, predict chance performance at judging constituent-order. As discussed below, prior results have suggested participants are above-chance on tests of constituent-order, as our results will also show. A pure convolution-based model must be rejected. However, given the success of convolution models at fitting a wide range of memory phenomena (e.g., Lewandowsky & Murdock, 1989; Metcalfe Eich, 1982; Murdock, 1982, 1995; Neath & Surprenant, 2003), it could be the case that convolution provides a good account of many association-memory phenomena, but that whenever constituent-order is needed, a different source of information is used. Admittedly less parsimonious, this leads to a specific prediction that we test in the present experiments: order-memory should be somewhat uncoupled from association-memory. That is, associations may be remembered without order, and possibly, order might be judged correctly even when the association cannot be remembered.

In contrast to convolution-based models, matrix models store associations by computing the outer product between two item-vectors, denoted $\mathbf{b}\mathbf{a}^{\mathrm{T}}$, where $^{\mathrm{T}}$ denotes the transpose operation, before being added to a memory matrix, M. Unlike convolution, the outer product is non-commutative: $\mathbf{b}\mathbf{a}^{\mathrm{T}} \neq \mathbf{a}\mathbf{b}^{\mathrm{T}}$. In fact, the forward and backward association are directly related to one another—one is the transpose of the other: $\mathbf{b}\mathbf{a}^{\mathrm{T}} = \left(\mathbf{a}\mathbf{b}^{\mathrm{T}}\right)^{\mathrm{T}}$. Because of this property, there are several ways, in the matrix-model framework, in which the order of constituent items might be distinguished. For example, multiplying a memory of one pair, $M = \mathbf{b}\mathbf{a}^{\mathrm{T}}$ from the right (Pike, 1984), $M\mathbf{a} \simeq \mathbf{b}$, but assuming $\mathbf{a}$ and $\mathbf{b}$ are dissimilar (very small dot product), probing in the opposite direction, $M\mathbf{b} \simeq 0$. Thus, assuming the model has access to this order information, one would predict that, if cued recall is successful, the model also has unambiguous knowledge of constituent-order. The matrix model also suggests that constituent-order and association-memory will be tightly coupled, and covary with one another both across pairs, and across participants, because order information is embedded within the association itself. This is in contrast to the modified convolution model, which implies independence. Pure matrix models may thus be insufficient if participants cannot always accurately judge constituent-order, whenever they successfully remember the association. Given the similar success of matrix-based models at fitting a wide range of phenomena (e.g., Anderson, 1970; Humphreys, Bain, & Pike, 1989; Pike, 1984; Willshaw, Buneman, & Longuet-Higgins, 1969), modifications to the basic operation of the matrix-model must be considered, as we elaborate in the General Discussion.

One could argue that the question of within-pair order has been overlooked by researchers because it does not correspond to an ecologically valid task. Indeed, our croissant–coffee example demonstrates that in many situations, constituent order is not important; one will receive both croissant and coffee, and any order (spatial or temporal) is acceptable. It is not difficult to come up with examples for which order does matter. For example, when first learning a person's name, note that first and last names are often drawn from different stimulus pools (e.g., Gordon Brown), in which case order may not need to be explicitly stored, but can be inferred from item-stimulus properties. Some names, however, are reversible (e.g., Simon Dennis versus Dennis Simon), in which case order must be explicitly stored. Compound words in English, which may be at the end of a continuum with novel associations (Caplan, Boulton, & Gagné, 2014), must be eventually learned with order, because they typically have a modifier–head relationship (e.g., Dressler, 2006). Thus, for example, a Jail–Bird means something different than a Bird–Jail; a Turtle-Neck must be something different than a Neck-Turtle. However, as we just showed, even models developed to explain association-memory for which order is irrelevant, implicitly lead to predictions about whether or not participants could perform well or poorly on order-judgement tests. Thus, our first goal was to measure order-memory ability when, during study, participants had no incentive to consider order, corresponding to the target-data that models of association-memory have been tested on (refer to the Order–Ignore groups in all three experiments). Our second goal was to see if order-judgements would be improved if order were made relevant, by instructing participants to attend to order and testing them with order-recognition on each iteration of the task (Order–Attend groups in all three experiments).

We identified a handful of studies that shed some light on the question of memory for constituent-order. First, research based on the so-called "double-function list" procedure (Primoff, 1938) has provided evidence that, in an association-memory task, participants have some moderate ability to discriminate order within associations. In double-function lists, each left-hand item of one pair is a right-hand item of another pair (AB, BC, CD, ...). Primoff (1938) found that the backward association ($B \rightarrow A$) interfered with participants' ability to retrieve the forward association ($B \rightarrow C$). Because participants were unable to completely rule out the backward association, memory for the order of constituents of a pair must not be perfect in that paradigm. Rehani and Caplan (2011) gave participants equal numbers of forward and backward cued-recall tests, of both double-function pairs and control pairs for which each item was present in only one pair, termed "single-function" pairs. If we assume the probability of recalling each associate (i.e., A, given B as the cue) were the same for double-function and for single-function pairs, the participant would presumably need to make a guess between the forward and backward associate if no order information were available. The prediction is that accuracy of double-function pairs should be one-half the accuracy of single-function pairs. If, at the other extreme, constituent-order were reliably stored (given that the association itself were stored), accuracy should be equivalent for double- and single-function pairs. In fact, accuracy was mid-way between these upper and lower bounds, suggesting that participants had some capacity to distinguish forward from backward associations, but imperfectly. It should be noted, however, that double-function pairs may have had one advantage over single-function pairs: each double-function item was presented twice, whereas for single-function pairs, each item was presented only once. It is possible that double-function pairs had greater item-memory, increasing the likelihood of retrieving the correct target item (cf. Criss, Aue, & Smith, 2011; Madan, Glaholt, & Caplan, 2010). If this item-memory advantage were large enough, it would inflate the level of double-function relative to single-function accuracy. Challenging this, Caplan, Rehani, and Andrews (2014) found that, in a similar paradigm that allowed participants to respond with both associates, accuracy was nearly identical for double-function as for single-function pairs, arguing against an item-memory advantage for double-function pairs. Still, the results from Rehani and Caplan (2011) are thus not entirely conclusive on the question of order-memory.

Also with a procedure based on paired-associate learning, Mandler, Rabinowitz, and Simon (1981) showed that, when asked to free-recall a list of pairs and report them in order when possible, participants were remarkably accurate at reconstructing constituent-order. This result suggests that, at least in some circumstances, constituent-order might be near-maximal.