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Is an attention-based associative account of adjacent and nonadjacent dependency learning valid?☆

Sébastien Pacton [a,b,c,*], Amélie Sobaco [a,b,c], Pierre Perruchet [d,e]

[a] Psychology Department, Université Paris Descartes, Paris, France
[b] Sorbonne Cité France, France
[c] INSERM, France
[d] Psychology Department, Université de Bourgogne, France
[e] CNRS, Dijon, France

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ABSTRACT

Pacton and Perruchet (2008) reported that participants who were asked to process adjacent elements located within a sequence of digits learned adjacent dependencies but did not learn nonadjacent dependencies and conversely, participants who were asked to process nonadjacent digits learned nonadjacent dependencies but did not learn adjacent dependencies. In the present study, we showed that when participants were simply asked to read aloud the same sequences of digits, a task demand that did not require the intentional processing of specific elements as in standard statistical learning tasks, only adjacent dependencies were learned. The very same pattern was observed when digits were replaced by syllables. These results show that the perfect symmetry found in Pacton and Perruchet was not due to the fact that the processing of digits is less sensitive to their distance than the processing of syllables, tones, or visual shapes used in most statistical learning tasks. Moreover, the present results, completed with a reanalysis of the data collected in Pacton and Perruchet (2008), demonstrate that participants are highly sensitive to violations involving the spacing between paired elements. Overall, these results are consistent with the Pacton and Perruchet's single-process account of adjacent and nonadjacent dependencies, in which the joint attentional processing of the two events is a necessary and sufficient condition for learning the relation between them, irrespective of their distance. However, this account should be completed to encompass the notion that the presence or absence of an intermediate event is an intrinsic component of the representation of an association.

1. Introduction

Nonadjacent dependencies refer to the cases where a statistical association exists between two events that are not immediately contiguous in space or time, due to the occurrence of one or several intervening events. This pattern is quite frequent in natural languages (e.g., between auxiliaries and inflectional morphemes, as in "is writing", irrespective of the verb stem). Nonadjacent dependencies are also present in other domains of high-level knowledge such as music. In Western music, for instance, two structurally important tones are often separated by other, less important tones (the ornaments). If the nonadjacent dependency between the two structurally important tones was not captured by the listener, the musical structure would not be perceived. Likewise, capturing the relationships between distant objects seems essential. As claimed by Turk-Browne, Jungé, and Scholl (2005), "People are constantly bombarded with noise in space and time that needs to be segregated in order to extract a coherent representation of the world, and people rarely encounter a sequence of relevant stimuli without any interruptions" (p. 562).

There is increasing evidence that the learning of nonadjacent dependencies is possible, but only under specific conditions (for a review: Perruchet, Poulin-Charronnat, & Pacton, 2012). Let us refer to a nonadjacent structure as AXC, where A and C stand for the associated events and *X* stands for a variable event, statistically independent from both A and C. A non-exhaustive list of conditions includes: (1) the high level of variability of the *X* event (Gómez, 2002, 2006; Onnis, Christiansen, Chater, & Gómez, 2003). (2) The high level of similarity between A and C. Similarity can be assessed on an acoustic dimension. Using musical tone sequences, Creel, Newport, and Aslin (2004) showed that nonadjacent dependencies were not acquired when all elements differed equally one another, whereas learning was successful when A and C were similar in pitch or timbre, and different from *X*. Likewise, Onnis, Monaghan, Richmond, and Chater (2005) showed that no

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* Corresponding author at: Université Paris Descartes, Laboratoire Mémoire et Cognition, 71 av E. Vaillant, 92100 Boulogne-Billancourt, France.
E-mail address: sebastien.pacton@parisdescartes.fr (S. Pacton).

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learning was obtained without some degree of phonological similarity between A and C syllables. (3) The membership of A and C to the same category, itself differing from the category of *X*. For instance, Newport and Aslin (2004) failed to observe learning with nonadjacent syllables (i.e., A, *X*, and C were syllables), whereas learning occurred when A and C were consonants and *X* was a vowel and, conversely, when A and C were vowels and *X* was a consonant. (4) The introduction of short pauses between the A*X*C sequences during the familiarization phase (Peña, Bonatti, Nespor, & Mehler, 2002). (5) The occurrence of an earlier training phase during which the to-be-associated pairs have been studied in adjacent conditions. Introducing structural complexity progressively during learning would meet the general learning principle known as the "starting small" effect (Lai & Poletiek, 2011).

Because adjacent dependencies are remarkably easy to learn in a large array of experimental settings, as shown throughout the associative learning literature, the restrictive conditions listed above have led some researchers to claim that learning adjacent and nonadjacent dependencies rely on different processes (e.g., Peña et al., 2002). In contrast with this dual-process view, Pacton and Perruchet (2008) proposed to account for both adjacent and nonadjacent dependencies within an integrated framework, grounded on the role of attention in associative learning (e.g., Hoffmann & Sebald, 2005; Hsiao & Reber, 1998; Jiménez & Méndez, 1999). Several authors have suggested that associative learning is an automatic process that links together all of the components that are present in the attentional focus at a given point (e.g., Frensch & Miner, 1994; Logan & Etherton, 1994; Perruchet & Vinter, 2002; Stadler, 1995; Treisman & Gelade, 1980) and that the joint attention given to a pair of events would be a necessary, but also a sufficient condition for the emergence of associative learning and memory. It is reasonable to postulate that, *by default*, the mental content composing the attentional focus at a given moment has a high chance of representing events that are close on spatial and/or temporal dimensions in the environment. This would account for the overt precedence to the condition of contiguity in the conventional associative learning literature. However, crucially, the attentional content may also encompass events that are not adjacent in the environment, although only if some specific conditions lead to pay joint attention to those events. In this regard, it is noteworthy that all the five experimental conditions listed above as beneficial for learning nonadjacent dependencies can be viewed as facilitating the attentional processing of the relevant events (i.e., A and C). Thus an attention-based account is seemingly able to retrospectively account for earlier data. More compellingly, this account is also able to generate testable predictions.

A straightforward prediction of the Pacton and Perruchet (2008) integrated framework is that conditions ensuring the very same amount of attentional processing for both adjacent and nonadjacent dependencies would result in a perfect symmetry between the two forms of learning. The authors reported a set of five experiments in which attentional processing was manipulated through the instructions given to the learners. Participants were faced with a set of problems, each comprising a sequence of digits embedding both adjacent and nonadjacent regularities. They were asked to perform an arithmetic task that involved the joint processing of two selected digits. These two digits were adjacent for a first group of participants, and nonadjacent for a second group. A subsequent recognition test explored how well participants from the two groups learned both adjacent and nonadjacent dependencies. The results were clear-cut. Participants who were asked to process adjacent elements learned adjacent dependencies but did not learn nonadjacent dependencies. Much more interestingly, participants who were asked to process nonadjacent elements learned nonadjacent dependencies but did not learn adjacent dependencies. It is noteworthy that the recognition score for nonadjacent dependencies was not significantly lower than the recognition score for adjacent dependencies reached by the participants who focused on adjacent dependencies. Thus, the objective adjacency of the events in the display played no role of its own when the attentional processing of A and C, as prompted by the task demand, was the same for each type of dependency (see also Jahn, 2012, for a replication).

Although Pacton and Perruchet (2008) data provided a strong support for an attention-based, unitary account of adjacent and nonadjacent dependencies, a potential limitation could be that their conclusion was based on experiments relying exclusively on digits as stimuli. Using digits instead of syllables or visual shapes, as commonly exploited in the statistical learning literature, was dictated by the need for creating a task that allows to focus on either adjacent or nonadjacent elements in a meaningful way. An arithmetic task is especially well-suited for this objective because processing nonadjacent digits is what anyone does while performing the most basic arithmetic calculations in real-world settings. However, the downside is that the processing of digits could be quite specific. The perfect symmetry found between the processing of adjacent and nonadjacent dependencies in Pacton and Perruchet could be restricted to this material. In particular, a possibility is that when there is no specific reason to pay joint attention to either adjacent or nonadjacent events, as in most standard tasks of incidental learning, the processing of digits would be insensitive to the contiguity condition which has been shown to be so important throughout the associative learning literature, or at least, less sensitive to the contiguity of the items than the processing of other stimuli such as syllables, tones, or visual shapes. A control condition using standard incidental instructions, such as listening to oral language or tones, or watching visual shapes, was not implemented in Pacton and Perruchet, and as a consequence, there is currently no evidence that the natural processing of digits would exhibit a strong preference for adjacent relationships, as regularly found for other stimuli.

The first objective of the present study was to explore the pattern of performance in a condition using neutral instructions, which was missing in the study of Pacton and Perruchet (2008). Neutral instructions refer here to a task demand that does not require the selective processing of either adjacent or nonadjacent dependencies, as in most incidental learning tasks. Participants were exposed to sequences of digits embedding both adjacent and nonadjacent dependencies, as in Pacton and Perruchet, but they were simply asked to read aloud the items. To examine further whether the processing of digits is endowed with particular properties, half of the participants performed the very same reading task with syllables. Our hypothesis was that under neutral instructions, the usual asymmetry between adjacent and nonadjacent dependency should be found for digits as for syllables, with easier, if not exclusive learning of adjacent dependencies. If this hypothesis turned out to be wrong, then the unified attentional model proposed in Pacton and Perruchet, grounded on the exclusive use of digits as stimuli, should be reconsidered.

Whereas most studies on nonadjacent dependencies deal with the conditions making learning easier, the "what is learned?" issue has not yet been extensively explored. The second objective of the present study was to shed preliminary light on a particular aspect of this issue, namely the status of the intermediate event (*X*) within the A*X*C sequence. In a nutshell, the question is: While learning A*X*C, does the learner simply code that A is followed by C, or is *X* a mandatory component of the learner's representation? The framework of Pacton and Perruchet (2008) does not deal explicitly with this question, but its emphasis on the role of the attention paid to the target stimuli, A and C, suggests that the intermediate event, *X*, must receive no, or only a minimal amount of attentional processing during training.

A recognition test including the correct sequence A*X*C and a distractor like A*X*D has often been used (e.g., Gómez, 2002). However, such a test is inappropriate to investigate whether *X* is a mandatory component of the learner's representation. Indeed, participants could express a preference for A*X*C over A*X*D simply because A and C, contrary to A and D, have formed the mental content of their attentional focus at a given time during the study phase, without having learned whether an intermediate element is located between A and C. In order to address this issue, distractors must include a spacing violation (e.g., A*X*C vs.