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Probabilities, Dependencies and Frequency Are Not All Equally Involved in Artificial Word Learning

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Introduction

The ability to learn first-order transitional probabilities (of an item B given a preceding item A in a sequence), second-order transitional probabilities (of an item C given the combination of two preceding items A and B), frequency of the AB pairs and adjacent or non-adjacent dependencies between A and B (i.e. with or without an item in between) is central to language processing in order to best adapt to the environment (Saffran, Newport, & Aslin, 1996; Pacton & Perruchet, 2008; Gebhart, Newport, & Aslin, 2009; Thiessen, Kronstein, & Hufnagle, 2013).

These **three factors** (Transitional Probability, Dependency and Frequency) have generally been studied separately in statistical learning of sequences, although they could interplay. For instance, a few studies that have addressed the combined effect of both transitional probabilities (TPs) and frequency have suggested a prevalence of TPs over frequency (Endress & Langus, 2017; Mirman, Graf Estes & Magnuson, 2010; Perruchet & Poulin-Charronnat, 2012; Lazartigues, Mathy & Lavigne, 2021). We decided to follow up on these studies using all three factors combined.

The present study investigated the role of transitional probabilities, frequency and adjacency in a single experiment on artificial word learning. Our hypothesis was that despite the increased complexity of our experimental setup manipulating simultaneously TPs, type of adjacency and frequency, optimal prediction of an item should predominantly depend on TP. First-order TP should be easier to learn than second-order TP and learning of TP should be better for adjacent dependencies and high frequency words.

Method

30 participants were exposed to four conditions composed each of 4 to-be-learned words made of 3 syllables. Each of the four conditions obeyed a specific rule, specified below. Note that the symbol * stands for a non-predictive syllable.

- ***BC** : The second syllable B predicted the third syllable C (B → C, corresponding to a first-order TP with adjacent items); the first item was random and could not help predict either B or C.
- **A*C** : The first syllable predicted the third (first-order TP, but non-adjacent).
- **ABC XOR** : this *exclusive-or* (XOR) allowed to test the effect of second-order TPs; only the combination of AB predicted C in a sequence ABC (second-order TP), all first-order TP in these sequences were equal to .5.
- **ABC XOR Unbalanced** : As above but with a manipulation of frequency. The two first words were presented 5 times per block (such as the words in other conditions), the third one was presented twice per block and the last one was presented 8 times per block. This corresponded to the respective frequencies 0.0625 for two words, 0.025 for the least frequent word and 0.1 for the most frequent word. Manipulation of the frequency led to a modification of the first-order TP and allowed to test the effect of the frequency and the first-order TP for a fixed value of the second-order TP.

The words were permuted randomly in each block. A trial consisted in a sequential presentation of each syllable at the center of the screen. Participants were instructed to perform a target detection task on two vowels which were only present in the last syllable. Note that upon correct learning, the last syllable C was predictable in all cases. Accuracy and response times (RTs) were recorded.

Each participant completed 5 sessions of 10 block (80 trials per block); one session by day for 5 days. A switch phase in a last block tested transfer with modified words. At the end of the experiment, a forced-choice task requested participants to choose between the learned words and lures obtained by using the same syllables as in the learned words.

Results

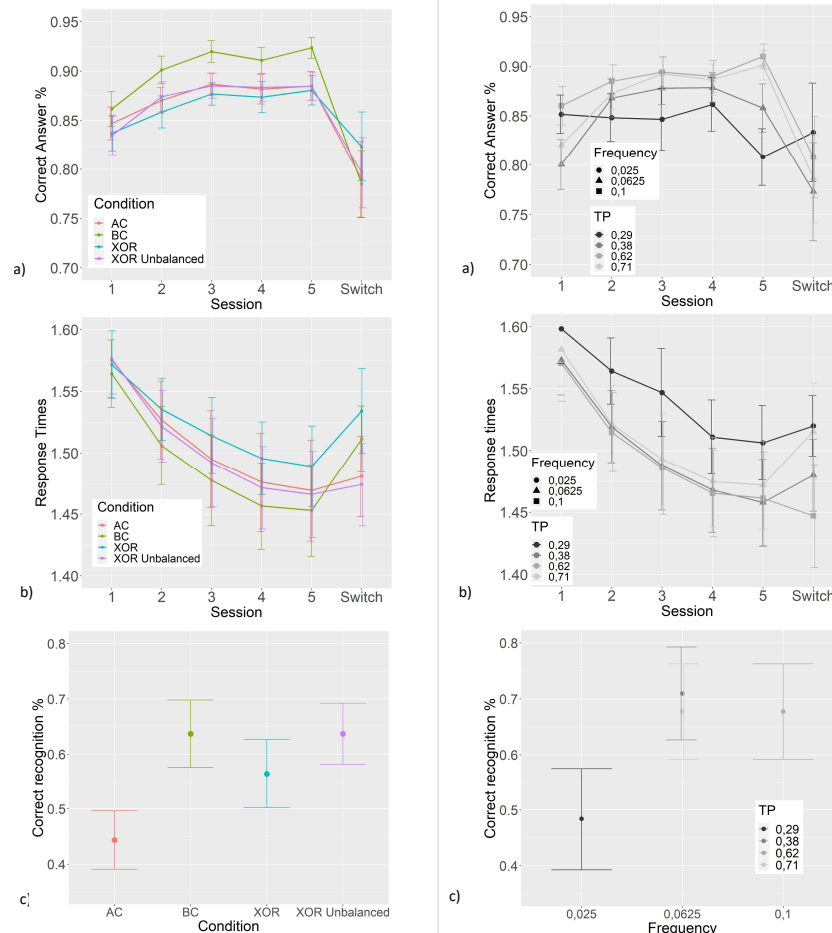


Figure 1
Effect of each condition on

- a) Accuracy,
- b) Response times,
- c) Correct recognition rate

Figure 2
Effect of frequency and transition probability (TP) in the Unbalanced XOR condition for

- a) Accuracy,
- b) Response times,
- c) Correct recognition rate

Principal findings

The results showed an increased rate of accuracy, a decrease of RTs during the learning phase, and a drop of performance during the switch phase for each condition (Figure 1a and 1b). This suggested that words were learned in each condition by the subjects. The results also indicated that adjacent first-order TPs (in condition *BC) were learned with the highest average accuracy compared to the three other conditions.

Regarding the condition XOR Unbalanced, our results showed that a low-frequency word resulted in a lower accuracy (resulting in an absence of drop of performance during the switch phase). A too low frequency thus appeared to hinder learning of new words (Figure 2a). Moreover, for equal values of frequency that were high enough to benefit learning, the results showed an effect of first-order TPs on accuracy, with higher performance for higher TPs (but with no significant effect on RTs).

The recognition task showed better recall of words for adjacent dependencies (Conditions *BC, XOR and XOR unbalanced) compared to non-adjacent dependencies (Condition A*C; see Figure 1c). Finally, we observed the worst recognition rate in the condition XOR Unbalanced (Figure 2c) for the least frequent word.

Conclusion

Consistent with our predictions and with a previous result (Lazartigues et al., 2021), our results show that statistical learning of TP in new words in a deterministic setting (i.e., no noise which would prevent predictions) is faster and more accurate for adjacent dependencies and high frequency words. Adjacent dependencies allowed better learning of TPs, with a clear advantage for first-order TPs but we still observe learning for second-order TPs. Moreover, TPs seemed the most efficient factor for learning, but a minimal frequency of the presented words was necessary to allow learning of TPs to occur.

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