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Attentional effects on rule extraction and consolidation from speech

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ABSTRACT

Incidental learning plays a crucial role in the initial phases of language acquisition. However the knowledge derived from implicit learning, which is based on prediction-based mechanisms, may become explicit. The role that attention plays in the formation of implicit and explicit knowledge of the learned material is unclear. In the present study, we investigated the role that attention plays in the acquisition of non-adjacent rule learning from speech. In addition, we also tested whether the amount of attention during learning changes the representation of the learned material after a 24 h delay containing sleep. For that, we developed an experiment run on two consecutive days consisting on the exposure to an artificial language that contained non-adjacent dependencies (rules) between words whereas different conditions were established to manipulate the amount of attention given to the rules (target and non-target conditions). Furthermore, we used both indirect and direct measures of learning that are more sensitive to implicit and explicit knowledge, respectively. Whereas the indirect measures indicated that learning of the rules occurred regardless of attention, more explicit judgments after learning showed differences in the type of learning reached under the two attention conditions. 24 hours later, indirect measures showed no further improvements during additional language exposure and explicit judgments indicated that only the information more robustly learned in the previous day, was consolidated.

1. Introduction

Prediction-based mechanisms appear to play a vital role in the detection of regularities that govern complex situations such as human language. Language contains adjacent and non-adjacent dependencies between elements that should be mastered to, for example, process 'recursion', which is a hallmark of human language (Hauser, Chomsky, & Fitch, 2002). Learning non-adjacent dependencies from language has been claimed to heavily rely on general prediction learning processes (Misyak, Christiansen, & Tomblin, 2010b; Perruchet & Pacton, 2006), which often occurs incidentally, i.e. without the intention to learn ("implicit learning"; Reber, 1967).

Previous research has evaluated non-adjacent rule learning using artificial language learning paradigms (see Gómez, 2002; Peña, Bonatti, Nespor, & Mehler, 2002; Romberg & Saffran, 2013), in which words or phrases without meaning are built following the structure AXC, establishing that the first element (A) predicts the third one (C), whereas the second element (X) is variable. These artificial paradigms are built as an analogy to what occurs in natural languages (e.g., **he** sleep**s**, **she** run**s**). Statistical learning mechanisms can track these predictive dependencies, extract the existing relationship and allow generalization to new contexts. However, an important question is the degree in which learning in incidental situations relies on attention. Some studies have provided evidence that segmentation of a speech stream into discrete word units can occur incidentally (Saffran, Newport, Aslin, Tunick, & Barrueco, 1997). In addition, rule generalization is possible under diverted attention but only as long as learning is based on adjacent dependencies (Toro, Sinnet, & Soto-Faraco, 2011; Toro, Sinnett, & Soto-Faraco, 2005). However, tracking non-adjacent relationships is more complex (Newport & Aslin, 2004). It has been proposed that the only necessary condition to learn adjacent and non-adjacent dependencies is the joint attention for the processing of the two elements in the dependency (Ellis, 2006; Pacton & Perruchet, 2008). In agreement with this view, some experiments

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have shown that the presence of pauses in the speech signal (Endress, Nespor, & Mehler, 2009; Peña et al., 2002) and the high variability of irrelevant elements in the sequence (Gómez, 2002) are essential for non-adjacent rule learning. Although these studies did not test the role of attention in the learning process directly, the importance of these features could reside in the enhancement of perceptual salience, guiding attention toward the elements that share the dependency (for a discussion about this topic, see Aslin & Newport, 2012; Romberg & Saffran, 2013).

Electrophysiological data using event-related potentials (ERPs) to track the online learning of non-adjacent rules in an artificial language learning paradigm have also shown that an attention-modulated ERP component, the P2 component, increases as a function of learning, which possibly indexes a change in the locus of the focus of attention during learning (from adjacent to non-adjacent dependencies) (De Diego-Balaguer, Toro, Rodriguez-Fornells, & Bachoud-Lévi, 2007) as previously suggested by Gómez and Maye (2005).

Importantly, understanding learning in incidental situations should not be limited to explicit judgments. It is also important to dissociate between the acquisition and storage of new information in relation to the implicit/explicit dimension (Frensch, 1998). During acquisition, knowledge can be initially encoded implicitly, as it often occurs in incidental situations. However, once learned, the invariant features (such as the dependency between non-adjacent elements) are enhanced and can eventually enter consciousness and become more explicit (Cleeremans, 2008). Most studies have not accounted for this distinction because they have only evaluated participants' performances after the learning phase when learning was accomplished (Saffran et al., 1997; Toro et al., 2011). Therefore, no information was available for online implicit learning while manipulating attention. In relation to this point, recent work has clearly shown the importance of introducing online measures in addition to the classical more explicit judgments after learning (Batterink, Reber, Neville, & Paller, 2015; Misyak, Christiansen, & Tomblin, 2010a; Misyak et al., 2010b).

Referring to how representations of the learned information change over time, previous evidence indicates that sleep promotes the lexicalization of new words (Davis, Di Betta, McDonald, & Gaskell, 2009; Tamminen, Payne, Stickgold, Wamsley, & Gaskell, 2010). In addition, it promotes the creation of abstract and generalizable representations in rule learning from language (Gómez, Bootzin, & Nadel, 2006; Merkx, Rastle, & Davis, 2011; Tamminen, Davis, Merkx, & Rastle, 2012). Importantly, sleep-related consolidation causes qualitative and quantitative changes in the mental representation of knowledge outside the language domain (for a review: Diekelmann & Born, 2010). Moreover, it plays an important role in promoting the conversion of implicit knowledge into explicit knowledge (Payne, Ellenbogen, Walker, & Stickgold, 2008; Wagner, Gais, Haider, Verleger, & Born, 2004).

Based on the above-mentioned background, the present study was developed with two different goals. First, our interest was to evaluate whether the amount of attention during the learning of non-adjacent rules affects differently indirect measures of learning and more explicit judgments on the underlying knowledge of the rules. Therefore, we developed a paradigm that allowed us to indirectly evaluate online rule learning in different attentional conditions. An artificial language learning task, in which the participants heard phrases of three artificial words that followed the form of AXC, was implemented with a word-monitoring task that acted as a cover task to manipulate attention. Thus, because learning the underlying dependencies helps to solve the cover task faster, the reaction times (RT) to the cover task provided an indirect online measure of implicit rule learning (Brandon, Terry, Stevens, & Tillmann, 2012; Misyak et al., 2010b). Explicit judgments were also used to assess rule learning by administering a recognition test to the participants after the learning phase. In addition, our secondary objective was to investigate whether attention affects the manner in which rule representations are consolidated leading to different effects in implicit and explicit assessments of this knowledge. Thus, participants' direct and indirect measures were recorded on two consecutive days.

2. Methods

2.1. Participants

Twenty-five students (19 women; mean age: 21.5 SD: 1.9) from the University of Barcelona participated in this study for either 10 euros or course credits. The students were all native Spanish speakers and had no history of auditory problems.

2.2. Materials and procedure

Each participant performed two sessions of the same language learning task (Experiment 1 and 2), separated by 24 hours. Each experiment consisted of a learning and a test phase (see Fig. 1A). For the experiments, 24 CVCV bisyllabic novel words (from now on called "words") were created following Spanish phonotactics. Words were recorded in isolation to avoid intonation cues, in a sound attenuated booth by a female Spanish native speaker. Afterwards they were combined with a sound editor software (Adobe Audition) to form the phrases, taking for each phrase three words from the pool of novel words (e.g., *tagi-male-sira*; Table 1) and inserting a 100 ms interval between words. The average duration of each word was 483.8 ms (± 39.7 ms). The auditory phrases were presented during the learning and test phases, through headphones at a comfortable level and set constant across participants with the Presentation software.

2.2.1. Learning phase

For the learning phase, words were combined to form rule phrases (AXC) and filler (XXX) phrases (Fig. 1B). Following the structure used in previous studies (Gómez, 2002; Gómez & Maye, 2005), *rule phrases* took the form AXC (e.g., **tagi**-male-**sira**, **tagi**-fuse-**sira**, **tagi**-pofi-**sira**) (Table 1), thus establishing that the initial word (A) determined the third word (C) regardless of the middle element (X). Six of the words from the pool were used to build three different AXC rules (i.e. A_1_C_1: tagi_sira; A_2_C_2: jupo_runi; A_3_C_3: pine_ladu). The remaining 18 (i.e. cilu, mego, lofa, tadi, nuso, pume, male, rosu, foli, vidu, supa, pevo, ture, medi, catu, gupe, defa, and nigo) were used as middle words for all A_C structures. Although over the three structures the 18 different words were presented, each structure used only 12 of the 18 X elements. The other 6, different for each structure, were used to test generalization in the recognition phase after learning. *Filler phrases* took the form XXX (e.g., *male-fuse-posi*) and were created by combining the 18 elements that randomly appeared in the middle of the rule phrases (i.e. X element in the AXC phrases) (Table 2). They were combined with the constraint that the same word could not appear twice in the same phrase and each X had the same probability to appear in each position. Each filler phrase was presented only once in the learning phase. These phrases appeared only in the learning phase (see Fig. 1B).

In the *learning phase*, the participants were exposed to 36 rule (see Table 1) and 18 filler phrases (Table 2) that were randomly intermixed. A 100-ms warning tone was used as an arousing signal to prepare the participants for the upcoming presentation of the phrase, which started 400 ms after the tone. Participants performed a word-monitoring task to obtain an indirect measure of learning by means of the reaction times to each phrase presentation. The target word remained printed in the middle of the screen