“THE COOLER YOU ARE, THE MORE I LEARN”
THE ROLE OF SOCIAL HIERARCHIES ON LEARNING: A PRELIMINARY STUDY

by

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Abstract

It is commonly assumed that having good teachers and proper learning methods is relevant in order to achieve academic success. Several studies on education research have shown how the behavioural performance is affected by these two elements; however, it is not known to what extent they also influence the neural physiology underlying the learning process.

The aim of this study was to deepen in this issue by comparing how the performance and ERP recordings of adult students changes during an explicit and an implicit learning task between two different contexts: one where the speaker is presented as pertaining to a higher hierarchy and one where the speaker is presented as pertaining to a lower hierarchy.

Our results suggest that both types of learning are influenced by the hierarchical context. While the effect on explicit learning is overtly reflected on the behavioural task, the influence on implicit learning is hidden in changes on the underlying neurophysiology. However, at the present time some of the results do not allow to draw ultimate conclusions about how they are influenced by the social hierarchies, so further experiments and analyses that would allow to unravel the effect are suggested.

INDEX

1. INTRODUCTION

If we go back in time and think about our school days, one of the first things that may come to our mind is the best teacher we had. Then, even though more unconsciously, we will link that time to all the knowledge we acquired during that period. Not surprisingly, it turns out that both a good teacher and proper learning methods are the essential elements that constitute education, not only in school, but also in higher education levels. As such, either how students perceive the teacher (Barber & Mourshed, 2007) or how they are instructed (von Elek & Oskarsson, 1972) can greatly influence the efficiency with which they learn.

In the present study we try to deepen in the influence of teacher status and learning method by comparing how the performance and ERP recordings of adult students during an explicit and an implicit learning task are modulated by two different social contexts: one where the speaker pertains to a high social hierarchy and one where the speaker pertains to a low social hierarchy.

1.1. THE ROLE OF SOCIAL HIERARCHIES

Human beings are intrinsically social and, as such, they must solve the problem that any social specie is forced to sort out, that is, social coordination. Following Cummins, “dominance hierarchies are the simplest and, by their very definition, least equitable solution” to this problem (Cummins, 2000). But, why did we evolve alongside the creation of social hierarchies? If we look at the animal world, we will see that social hierarchies are an ubiquitous principle of social organization across many species, which might suggest that they are a general biological mechanism. Actually, the creation of social hierarchies developed in order to ensure survival and reproductive success and it is, in fact, nothing less than an expression of the natural selection process (Cummins, 2006). According to natural selection, only the genes of those who live long enough to reproduce will remain in the gene pool and will be transmitted to the next generation. Given that the existence of dominance, status or rank implies that some individuals have “priority of access to resources in competitive situations” (Clutton-Brock & Harvey, 1976; Cummins, 2000) it is not surprising that in most species there is a direct correlation between reproductive success and social status: individuals who have a higher status are less likely to die of predation or starvation and, thus, more likely to leave offspring (Clutton-Brock, 1988).

Even though we do not think much about our social status, as any other social animal we are governed by the same principle. In fact, social hierarchies among humans emerge early in development: fifteen-month old toddlers are already able to perceive hierarchical patterns as stable attributes of a relationship, and they are also aware of the differences that this implies, as they prefer to join and imitate high status individuals (Boyce, 2004; Cummins, 2000; Mascaro & Csibra, 2012). Later, among adults, hierarchies have an evident and significant role in our everyday life (in domestic, work and recreational settings), where they drive individuals to act according to a behaviour that fits their "place" in the hierarchy (Cummins, 2000).

The behavioural changes triggered by social hierarchies depend on two main phenomena that are closely related: the aims of an individual and how the status of others is perceived. The term *level of aspiration* (coined by the theories of Festinger and Sears; Festinger, 1954; Sears, 1940) refers to the degree of performance that a person considers as "good" and, thus, expects to achieve. In a typical experimental setting, a participant is given a task that encompasses a series of trials; after each trial, the participant is told her/his score, and is asked to tell what score s/he expects to get in the next trial. In the absence of comparison with other people the level of aspiration fluctuates in parallel to performance (i.e. depending on previous scores). However, it was observed that when an individual can compare her/his performance with the performance of others, the level of aspiration becomes somehow determined: it tends to move closer to the level of performance of the other person and, consequently, the individual will change her/his behaviour in order to reduce discrepancies that exist between them (Dreyer, 1954). Recent studies have explored the possibility that this change in performance comes from the influence of the hierarchical context on attention, which is essential to achieve an empathic contact with others, as well as to discover potentially relevant information in the environment. For instance, it has been shown that the gaze cuing effect (i.e. shifting of attention in the direction gazed by conspecifics) is greater for high-status faces than for low-status faces (Dalmaso *et al.*, 2011). This suggests that attention can be actually modulated by top-down influences that, in this case, are triggered by the social hierarchy context.

There is at present evidence that both the perception of social hierarchies and its impact on attention do have several neuroanatomical correlates. It has been described that viewing a superior individual engages dorsolateral prefrontal cortex activation, which has been linked with enhanced recruitment of perceptual and attentional processes in the presence of a higher status person (Zink *et al.*, 2008). Actually, electrophysiological data do support this: when participants view high hierarchy faces there is higher amplitude in the N170 ERP component (linked to face processing) (Chiao *et al.*, 2008), and in the N1 component (linked to sensory and perceptual processes) (Santamaría-García *et al.*, 2013a). Besides, it has been suggested that perceived social rank of speakers does also influence their credibility (Santamaría-García *et al.*, 2013b). Strikingly, in this study there were no traces of social hierarchy effect in participants' overt judgements, but just in the electrophysiological response: high plausibility sentences uttered by a low hierarchy speaker elicited higher N400 amplitude than when they were uttered by a high hierarchy speaker, thus indicating that some semantic anomaly was detected or, indeed, that participants did not trust the low ranking speaker.

1.2. EXPLICIT AND IMPLICIT LEARNING

Aprendre (the Catalan word for *learning*) has its origin in the Latin word *apprehendere*, which means *catch* or *take*. Actually, the American Psychological Association (APA) defines *learning* as "the *acquisition* of knowledge or skills through study, experience, or being taught". As such, learning involves combining and synthetizing different kinds of information. In fact, learning should be conceived as a process, as it is influenced by our previous knowledge and, in turn, it influences our subsequent behaviour (Joshi *et al.*, 2014). Learning can be classified according to many different factors. However, given the scope of the present study, it will be henceforth classified depending on the awareness of the learner, that is, explicit and implicit learning. Actually, this classification is of crucial relevance for the educational community, as it finds an analogous division in the way the teacher can present the material to the students, namely explicit or implicit instruction.

On the one hand, explicit instruction happens when the teacher clearly outlines what are the goals for the student and offers overt explanations about the presented information; it leads to explicit learning, which is the conscious and intentional recollection of information (Graf & Schacter, 1987). This kind of learning highly relies on attention, since the subject must be specifically focused on the previously outlined goal for explicit learning to be successful.

On the other hand, implicit instruction refers to a teaching style where the instructor does not outline such goals but simply presents the information to the student and allows him to assimilate it by creating his own conclusions or conceptual structures; it leads to implicit learning, which is "the primitive process of apprehending structure by attending to frequency cues" (as defined by Reber in 1976) or, in other words, learning without intention and without awareness of what is being learned (Reber *et al.*, 1999). This does not mean that this kind of learning does not need attention; actually, it is commonly accepted that learning *per se* requires attention. However, several studies exploring the effect of secondary tasks on implicit learning show that, despite under this condition it is impaired, it still takes place (Cohen *et al.*, 1990): this suggests that the impact of attention on implicit learning is much lower than its impact on explicit learning.

Anatomically, different neural networks are recruited depending on whether subjects are aware or not of the material they learn (see Reber, 2013 for a recent review). While explicit learning relies on the specialized circuitry of the medial temporal lobe (MTL), implicit learning depends on more diffuse brain networks: actually, several neuroimaging studies show that implicit learning occurs through changes in different processing systems across the brain. It is noteworthy that both the MTL and the widespread correlates of implicit learning would be activated simultaneously during learning, since most situations involve both kinds of learning, with varying amount of contribution from each (Sun & Mathews, 2005; Sun *et al.*, 2001).

Regarding methodological approaches to assess explicit and implicit learning, there are also several differences between both types of learning. On the one hand, explicit learning is relatively easy to assess, as any activity in which the goal is clearly explained constitutes a successful explicit learning task. On the other hand, assessment of implicit learning is quite more challenging, since it requires the participant to be unaware of what s/he is actually learning. Despite this, there are three main well-established paradigms to test implicit learning: artificial grammar learning, sequence learning and control of dynamic systems (see Dekeyser, 2003 for a review). The present study relies on the first one, that is, the construction of an artificial grammar (AG) that follows the principles of the Markovian finite state grammar (Chomsky & Miller, 1958), whereby after exposition to this AG participants are asked to judge whether new items follow the rule or not.

In all of these paradigms subjects do learn but, yet, they are unaware of "what" they have learned and find it difficult (or even impossible) to communicate to others what they know. So, how do they learn the implicit information hidden in the stimuli? Actually, the original definition from Reber for implicit learning already answers this question: participants are able to implicitly learn through the detection and representation of the statistical features hidden in the stimuli. According to this, Saffran and collaborators coined the term *statistical learning* to specifically designate the ability of infants to extract words embedded in a continuous artificial language (Saffran *et al.*, 1996). Even though implicit learning and statistical learning refer to the same phenomenon (they both happen unconsciously), they account for different underlying computational processes: in the former participants rely on the formation of chunks or fragments to code the information, whereas in the latter they perform statistical computations based on the transitional probabilities between successive elements (see Perruchet & Pacton, 2006 for a review). Interestingly, these two kinds of computations are not considered to be exclusive of each other but, rather, they may combine to achieve successful implicit learning (Saffran, 2001; Servan-Schreiber & Anderson, 1990).

1.3. LANGUAGE-RELATED ERP COMPONENTS

Since the first publications on event-related brain potentials (ERPs) and language processes in the 1980s, there have been plenty of studies on the electrophysiology of language. Consequently, there are many ERP components that have been described as reflecting language processing. Here, I will present those that, according to previous literature (De Diego *et al.*, 2007; Kaan *et al.*, 2000; Kutas & Hillyard, 1980; Näätänen, 1990), are relevant for the present study and will help to assess explicit and implicit learning, namely the P200, the N400, the P600, and the P300.

The P200 (or P2) is a positive waveform that peaks around 200 ms after stimulus-onset, with a time window that ranges from 120 to 220 ms, and is mainly located around the centro-frontal region. It usually occurs together with the N1 component, forming the N1-P2 complex. This complex is known to be an onset response to changes in acoustic environment. However, while the N1 component reflects the detection of an acoustic change and is sensitive to the physical characteristics of the sound used to evoke the response (see Picton, 2013 for a recent review), the P2 component is thought to reflect auditory processing beyond sensation (Crowley & Colrain, 2004). Several experiments showed how voice-onset time (VOT) training modified the N1-P2 complex (Alain *et al.*, 2010; Sheehan *et al.*, 2005; Tremblay *et al.,* 2001): basically, their results did not reveal any modifications in the N1 component but, rather, they found that P2 amplitude increased following VOT training. Subsequent experiments showed that the enhancement in P2 amplitude was not specific to auditory perceptual learning; more precisely, it was found to be a marker of auditory rule learning when elicited in frontal regions (De Diego *et al.*, 2007). The notion that increase in P2 amplitude is the physiological correlate of auditory learning has also been challenged by the idea that there may be other processes that contribute to this gain: for instance, stimulus exposure, attention and memory are also inherent in any auditory training paradigm, and they could influence P2 changes (Sheehan *et al.*, 2005). Actually, Tremblay and colleagues (2014) found that P2 amplitude gains were observed both for participants who did and did not learn the presented VOT contrast: they concluded that P2 modulations should not be considered as a marker of the learning outcome but, rather, they might reflect changes in neural activity associated with the acquisition process.

The N400 is a negative voltage peaking around 400 ms after stimulus onset (window ranging from 300 to 500 ms) and it is typically maximal over centro-parietal electrode sites. Kutas and Hillyard (1980) first described this component with a task that involved the comparison of sentence-final words that formed predictable endings against those that were semantically improbable: the latter was found to elicit a larger negative waveform in the time range that corresponds to the N400. Despite the N400 is generally considered the correlate of semantic processing, its functional interpretation has led to discrepancies (see Kutas & Federmeier, 2011 for an exhaustive review). While some studies present the N400 as a reflection of the cost of integrating a word in a semantic context (Kutas *et al.*, 2006), there is also solid evidence that accounts for the N400 as reflecting the amount of cognitive resources invested in recognizing a word. For instance, Curran (2000) showed that the N400 amplitude varied with the familiarity of presented words, that is, new words elicited a greater N400 than already studied words; interestingly, they also presented words that were similar to the studied ones (pluralized by adding an *s*), but the N400 amplitude elicited by them was similar to that of the studied words.

The P600 is a late positivity that peaks around 600 ms (window ranging from 500 ms to 1 s), which is mainly located in posterior electrodes. Despite it is generally associated to agreement and morphosynctactic violations, it is often divided into two subcomponents that reflect two different functional stages (Brown & Hagoort, 2000; Kaan & Swaab, 2003). On the one hand, the early stage (from 500 to 750 ms) has a wider distribution over the scalp, and has been also found in frontal regions (Friederici *et al.*, 2002; Kaan & Swaab, 2003); it is thought to represent the difficulties in integrating the violation with the previous sentence fragment (Kaan *et al.*, 2000). On the other hand, the later stage (from 750 ms to 1 s) is confined to posterior regions of the scalp, and would represent the reanalysis and repair processes that take place after the detection of the violation (Barber & Carreiras, 2005). It is noteworthy that the P600 effect strongly correlates with the frequency and saliency of the morphosynctactic violations (Coulson, King, & Kutas, 1998).

Even though the P300 is not directly linked to any specific feature of language, it has a close relationship with target detection, a key piece of the task presented in the present study (see Methods, 2.1.2.). Chapman and Bragdon first described the P300 in the mid-1960s (Chapman & Bragdon, 1964): in their experiment, participants were shown two kinds of stimulus (numbers and flashes of light) one at a time in a sequence, and they were asked to make simple decisions upon numbers. On top of sensory-related ERPs, Chapman and Bragdon found a differential component between numbers and flashes: numbers elicited a positivity peaking around 300 ms (i.e. P300), whereas flashes did not. The authors suggested that the observed P300 could be linked to the fact that, in this task, numbers were meaningful to the participants. Subsequent studies support this original idea, expanding the findings from the visual to the auditory domain (Sutton *et al.*, 1965), and emphasizing that, more than meaning, what modulates the P300 is probably the required attention to the particular kind of stimulus. For instance, it has been shown that, in the Oddball paradigm, there is larger P300 amplitude for target items compared to standard items, and its amplitude inversely correlates with the frequency of the target items (Duncan-Johnson *et al.*, 1977; Katayama & Polich, 1998). Similarly as it happens in the P600, the P300 is composed of two subcomponents, P3a and P3b. The P3a (novelty P3) has an earlier onset window (from 250 to 280 ms) and a frontocentral scalp distribution; it has been suggested to reflect passive comparisons during task processing, as its amplitude is larger for the infrequent stimulus regardless of attention (Katayama & Polich, 1998). The P3b (classic P300) has a wider window (from 250 to 500 ms) and it is associated with posterior scalp activity; it has been linked with recognition and memory processing, and it strongly depends on where attention is placed (Näätänen, 1990).

1.4. THE PRESENT STUDY: AIMS AND HYPOTHESES

The main goal of the current work was to test the effect of social hierarchies (high and low rank speaker) on implicit and explicit learning, both at the behavioural and neural level. In order to assess explicit and implicit learning, two different artificial languages following an AG paradigm were created (one for each social rank condition). The task started with a learning phase (LP) where one of the languages was presented and during which participants had to focus on the last word of each sentence. Then, participants had to solve two tests where they had to discriminate between words and non-words, and rule and non-rule sentences, which evaluated explicit (ET) and implicit (IT) learning, respectively.

The main goal was achieved throughout three experiments. First, in Experiment 1 the aim was to develop and optimize the materials and task for the subsequent experiments. Thus, Experiment 1 was performed as a behavioural pilot to check that both languages could be considered similar and that neither of the languages nor tests was too difficult. In order to consider that both tests had an appropriate level of difficulty, we expected the percentage of correct answers to be between 70 and 85% (for both the ET and IT).

Second, Experiment 2 was the behavioural and electrophysiological control for Experiment 3. It had the same two aims of Experiment 1, as well as the identification of the aforementioned ERP components in the corresponding phase of the task. Particularly, we expected a gradual increase of P200 amplitude along the LP as a marker of both explicit and implicit learning (depending on its location); higher P300 (P3b) amplitude for words (i.e. targets) that for non-words, but higher N400 amplitude for non-words that for words during the ET; and higher P600 (early P600) amplitude for non-rule than for rule sentences during the IT.

Finally, in Experiment 3 we tested the impact of high and low social hierarchy context. Previous research has shown that high rank faces draw more attention than low rank faces (Chiao *et al.*, 2008; Santamaría-García *et al.*, 2013a; Zink *et al.*, 2008), and that the impact of attention is different for each type of learning. The novelty of this study emerges from the combination of these two factors, where we expected that the effect of each hierarchical context would be different depending on the type of learning. Our hypothesis was that, when compared to the control condition (Experiment 2), explicit learning would be highly influenced by the hierarchical context (specially by the high hierarchy), whereas implicit learning would not experience such modulation or, if so, it would be more attenuated. Therefore, behaviourally, we expected that in the ET the high hierarchy speaker would induce improvement of performance, whereas for the low hierarchy speaker it would be lower or remain unchanged; no effects were expected in the performance of the IT. Similarly, in the electrophysiological signal we expected that the ERP components linked with explicit learning would be more modulated in the presence of the high hierarchy speaker, but there would be no change of modulation (or milder effect) in the presence of the low hierarchy speaker; for the ERP components linked with implicit learning we expected no change of modulation, neither in the high nor in low hierarchy context.

2. MATERIALS AND METHODS

2.1. EXPERIMENT 1

2.1.1. Participants

A group of 12 right-handed Catalan or Spanish native speakers (all females, mean age: 22.17, range 18-26 years) participated in this experiment. They were recruited at Universitat Pompeu Fabra and were paid 10€ for their participation in this experiment.

2.1.2. Materials and procedure

Languages. Since in Experiment 3 the speakers (high and low rank) would use different languages, two artificial languages were created and tested in the present experiment. Both languages were synthesized with M-Brola, using a female Spanish native voice. Each syllable had a duration of 120 milliseconds and a frequency of 240 Hz. It was rigorously controlled that neither the words nor the sentences matched real words in Catalan or Spanish. For each language, 48 sentences of different length (formed by 2, 3, 4 or 5 noun phrases) were constructed following the same specific implicit rule, so that each noun phrase was formed by one short word and one long word. Table 1 shows the rules used to form noun phrases and sentences, taking as example the words of Language A. More detailed examples (for both Language A and B) are in Appendix 7.2.1 (Tables A, B and C).

<u>Table 1.</u> Short words and long words of Language A, and rules used to form noun phrases and sentences.

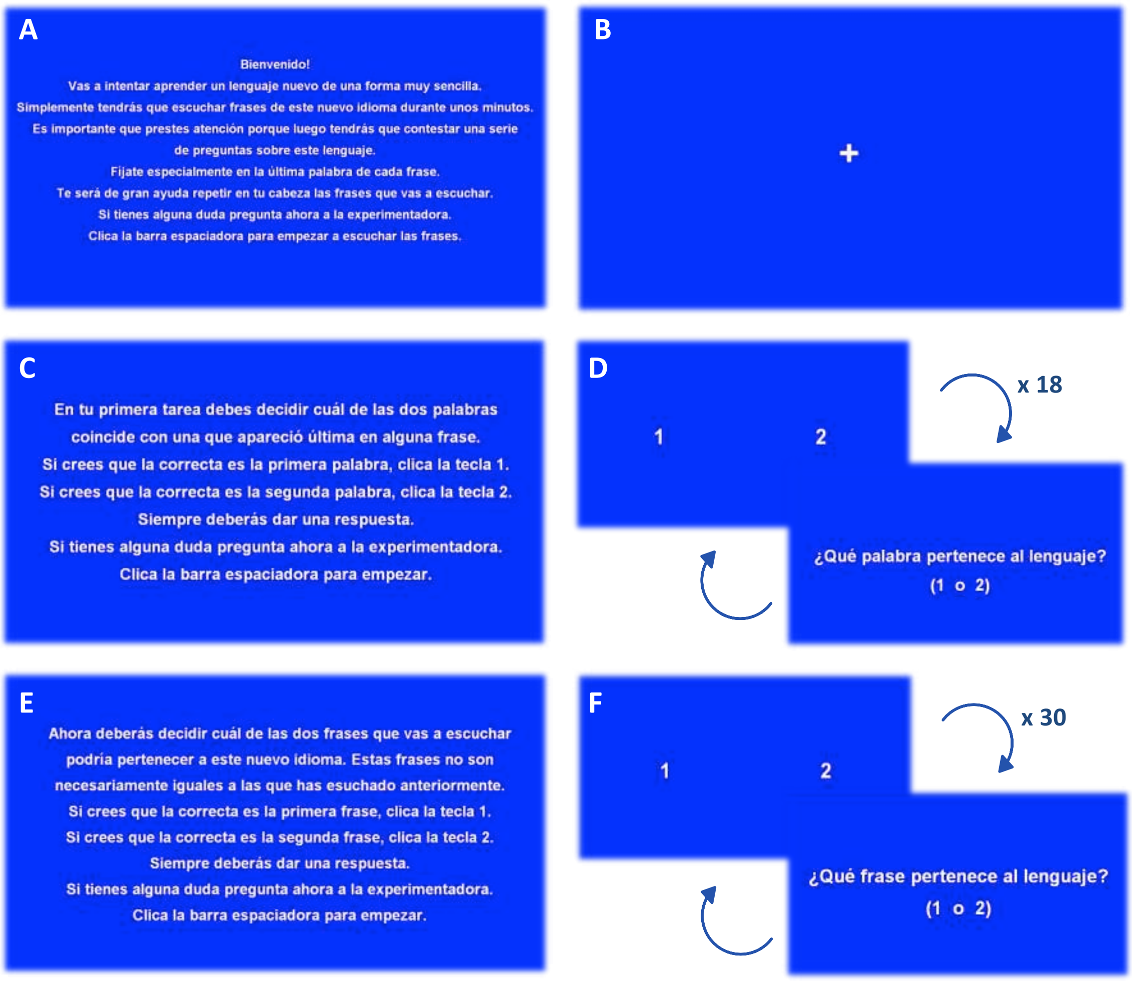
<table>
<tr><th colspan="4">Short words</th><th colspan="2">Long words</th></tr>
<tr><td>A</td><td>B</td><td>C</td><td>D</td><td>1</td><td>2</td></tr>
<tr><td>pu
ko</td><td>ne
ji</td><td>rra
mu</td><td>fo
ga</td><td rowspan="3">tirre
fusa
erpo
danu</td><td rowspan="3">kalu
niba
doñi
guison
fedu
lemo</td></tr>
<tr><th colspan="4">Rule to form noun phrases</th></tr>
<tr><td colspan="4">{A, D} combine with {1, 2}
{B, C} combine with {2}</td></tr>
<tr><th colspan="6">Rule to form sentences</th></tr>
<tr><td colspan="6">B2 → D1 → C2 → D2
B2 → A2 → A1 → C2 → D2
2 noun phrases
3 noun phrases
4 noun phrases
5 noun phrases</td></tr>
</table>

For the explicit-learning test, the last long words of 18 sentences were selected to set the Word condition; the Non-words could follow four kinds of violations, though in the present research they were considered as a single category. For the implicit-learning test, 30 sentences were selected to set the Rule condition; the Non-rule sentences could follow three kinds of violations but, again, they were taken as one category for the analyses. Details and examples of the violations of Words and Rules (for both languages) are in Appendix 7.2.1 (Tables D, E, F, G).

Task. Participants performed the experiment in a soundproof and Faraday cage room at the Neuroscience Laboratory of the Centre for Brain and Cognition, in Universitat Pompeu Fabra. During the task, participants sat in a comfortable chair in front of the computer monitor. They listened to the auditory stimuli (languages) binaurally through headphones (Sennheiser HD 435 Manhattan). Two artificial languages were tested, so the whole experiment lasted around 35 minutes (17 minutes for each language). The order of the languages was counterbalanced across participants. The task was divided into 3 phases (see Box 1). Participants were told that, they would listen an artificial language and that later they would have to perform two tests; more detailed instructions were given written before each phase. In the first phase, called learning phase (LP), participants listened for 8 minutes to an artificial language. This stage consisted of 3 identical blocks of 2 minutes and 40 seconds each, and in each block they listened to 48 sentences that were randomly ordered; there was 1 second of silence between sentences and a fixation cross was presented on the screen during the whole LP. In the instructions for this phase, participants were told to focus on the last word of each sentence. Sentences of different length appeared mixed in order to maintain the attention of the participants. The second phase was the explicit-learning test (ET). This test had 18 trials, and in each trial the participants were presented with a word and a non-word; the order of the word/non-word pairs was randomized across participants, and the word appeared randomly across trials in either the first or second position. Numbers “1” or “2” were presented on the screen when the first and second options were played, respectively. Then the question “¿Qué palabra pertenece al lenguaje? (1 o 2)” was presented, and participants had to answer by pressing “1” or “2” in the keyboard. The third phase was the implicit-learning test (IT). This test comprised 30 trials, and in each trial the participants listened to a sentence following the rule, and a sentence with a violation of the rule; the order of the rule/non-rule sentence pairs was randomized across participants, and the rule sentence appeared randomly across trials in either the first or second position. Again, numbers “1” or “2” were presented on the screen when the first and second options were played, respectively. Then the question “¿Qué frase pertenece al lenguaje? (1 o 2)” was presented, and participants had to answer by pressing “1” or “2” in the keyboard. At the end of the whole experiment (i.e. after both languages), participants were asked three questions: what the difficulty of the task was (from

0=easy to 10=difficult); if during the LP they had focused on the last word of each sentence or on the whole sentence; and if they had detected any rule or pattern embedded in the languages when listening to the sentences.

Box 1. Phases of the experiment. A) Instructions for the LP. B) Screen displayed during the LP. C) Instructions for the ET. D) Screen displayed during the presentation of the two options in the ET and subsequent question. E) Instructions for the IT. F) Screen displayed during the presentation of the two options in the IT and subsequent question.



2.2. EXPERIMENT 2

2.2.1. Participants

A group of 16 right-handed Catalan or Spanish native speakers (all females, mean age: 22.04, range 19-25 years) participated in this experiment. None of them had participated in Experiment 1. Two of the participants were excluded because of very low performance in the tests (percentage of correct answers in the ET and IT lower than 50%). Participants were recruited at Universitat Pompeu Fabra and were paid 15 or 20€ for their participation in this experiment (the amount depended on the time spent, as the preparation of the actiCap slightly varied among individuals). All of them signed the corresponding written informed consent.

2.2.2. Materials and Procedure

Language and Task. Same as in Experiment 1.

Electrophysiological recording. The EEG signal was recorded using a BrainAmp amplifier and the Brain Vision Recorder software (Brain Products GmbH). The ERPs were recorded from the scalp using tin electrodes mounted in an actiCAP (Brain Products GmbH) and located at 60 standard positions (Fp1, Fp2, AF7, AF3, AF4, AF8, F7, F3, F1, Fz, F2, F4, F8, FT9, FT7, FC5, FC3, FC1, FC2, FC4, FC6, FT8, FT10, T7, C5, C3, C1, Cz, C2, C4, C6, T8, TP9, TP7, CP5, CP3, CP1, CPz, CP2, CP4, CP6, TP8, TP10, P7, P5, P3, P1, Pz, P2, P4, P6, P8, PO9, PO3, POz, PO4, PO10, O1, Oz, O2). Eye movements were measured with electrodes attached to the infra-orbital ridge and the outer canthus of the right eye. The EEG recording was referenced online to the right mastoid and re-referenced offline to linked mastoid. Electrode impedances were kept below 25 kOhm (ground and reference below 10 kOhm). The electrophysiological signal was filtered online with a bandpass of 0.01-50 Hz and digitized at a rate of 500 Hz.

Electrophysiological data analyses. ERPs were recorded during the LP, the ET and the IT. The electrophysiological signal was analysed using Bran Vision Analyzer 2.0 software (Brain Products GmbH). For the LP, epochs were time-locked to the beginning of the first and last long word of each sentence: these two locations were chosen because they would allow to analyse changes in learning-related ERPs through the blocks, both in explicit learning (time-locked to the beginning of the last long word: participants had to focus on the last word) and implicit learning (time-locked to the beginning of the first long word) (Table 2). For both the ET and IT, epochs were time-locked to the location where the violation appeared in the non-words and non-rule sentences, respectively (Table 2), and only correctly answered trials were included.

<u>**Table 2.**</u> Examples of the location where epochs were time-locked in each phase of the experiment (the red arrow shows the location of the triggers).

LP	**Example of 3 noun phrases sentence**: ..._ ji kalu pu lemo ko tirre _...
ET	**Word**: danu **Non-word**: fonu
IT	**Rule sentence**: ji kalu fo tirre **Non-rule sentence**: ji kalu ti rrefo

In all cases epochs included a pre-stimulus baseline of 100 ms, and were 1500 ms long. ERPs were averaged offline for each participant and condition. All of the time windows were determined by visual inspection of the grand-average waveforms. In the LP it was analysed the P200 modulation on frontal and fronto-central electrodes (AF3, AF4, F3, F1, Fz, F2, F4, FC5, FC3, FC1, FC2, FC4, FC6) within the 150-220 ms window. In the ET, it was analysed the P300 and the N400. The P300 was analysed in parietal and occipital electrodes (P7, P5, P3, P1, Pz, P2, P4, P6, PO3, POz, PO4, PO9, O1, Oz, O2, PO10) within the 290-350 ms window; the N400 was analysed on central and frontal electrodes (AF3, AF4, F3, F1, Fz, F2, F4, FC5, FC3, FC1, FC2, FC4, FC6, C3, C1, Cz, C2, C4, P5, P3, P1, Pz, P2, P4, P6) within the 350-850 ms window. In the IT, it was analysed the P600 on parietal and centro-parietal electrodes (CP5, CP3, CP1, CPz, CP2, CP4, CP6) within the 500-800 ms window.

2.3. EXPERIMENT 3

2.3.1. Participants

A group of 28 right-handed Catalan or Spanish native speakers (all females, mean age: 22.21, range 18-29 years) participated in this experiment. None of them had participated in Experiments 1 or 2. They were recruited at Universitat Pompeu Fabra and were paid 15 or 20€ for their participation in this experiment (the amount depended on the time spent, as the preparation of the actiCap slightly varied among individuals). All of them signed the corresponding written informed consent.

2.3.2. Materials and procedure

Languages. Same as in Experiments 1 and 2.

Social videos. Four different videos (1 minute 30 seconds each) were created, in which two female confederates interpreted two different profiles. These profiles presented personal, academic and professional achievements in a way that depicted different hierarchy status (high and low). Implicit cues related to social status were controlled (age, facial expressions, intonation and attire). Details of the scripts interpreted by the confederates can be found in Appendix 7.2.2 (Boxes A and B).

Task. Due to the lack of time to collect data from a sufficiently large number of participants, it was decided to block the factor Language with the factor Hierarchy, so that in this experiment Language A matched High hierarchy and Language B matched Low hierarchy. Moreover, the task differed from Experiments 1 and 2 in three aspects. First, at the beginning of the task the social video (either High or Low hierarchy profile) was presented to set the social context. Second, the instructions for each stage of the task were given through short videos by the character presented at the beginning, in order to maintain the social context. Third, while participants were listening to the stimuli during the LP, ET and IT, a picture of the character was presented on the screen, also to maintain the social context (see Boxes C and D in Appendix 7.2.2). The order of the hierarchies and confederate playing the profile was counterbalanced across participants.

Electrophysiological recording. Same as in Experiment 2.

Electrophysiological data analyses. Same as in Experiment 2.

3. RESULTS

3.1. EXPERIMENT 1 (results and discussion)

First, to check that both languages could be considered similar, an ANOVA with factors Language and Order was performed, both for the explicit-learning test (ET) and the implicit-learning test (IT). For the ET there was a main effect of Order ($F_{(1,20)}$=6.31, p<.05) as well as a significant interaction between Language and Order ($F_{(1,20)}$=8.26, p<.01): while in Language A the tendency was to increase the percentage of correct answers from the first to the second position, in Language B the tendency was to decrease (S1A; ANOVA: S2A). The pattern of Language A was not surprising, because it meant that during the first language participants had learnt how the task worked; however, the pattern in Language B was unexpected. Nevertheless, given that this effect could be due to the small sample of participants, it was decided to go ahead with Experiments 2 and 3, whose results might help to clarify this point. For the IT there were no significant main effects or interactions (S1B; ANOVA: S2B). However, as it was expected, when participants performed the test for the second language, there was a general trend to increase the hit rate. Again, this meant that during the first language participants learned how the task worked: indeed, nearly half of the subjects reported that, since in the first language task they were asked about whole sentences, during the second language task they had focused both on the last word and on the whole sentence.

Second, the difficulty of the tests and languages was analysed: the means of the hit rates for the ET ranged between 70-85%, and for the IT they ranged between 59-65% (Fig. 1). The results for the ET fell within the ranged we aimed at. However, the “slightly-above-chance” performance in the IT might point to a higher than expected difficulty of the rule embedded in the language. Accordingly, all participants rated the task with a level of difficulty of 7 or 8 (mean=7.21), and none of them had detected any rule or pattern related with the grammar upon which the Languages were created. Actually, the fact that they were not able to specify the rule, but just infer that some regularity was happening, ensured that the rule was implicit.

3.2. EXPERIMENT 2 (results and discussion)

3.2.1. Behavioural results

The statistical analyses were the same as in Experiment 1, and similar results were obtained. The main difference was that, for the ET, the ANOVA with factors Language and Order showed no interaction between these two factors, suggesting that the anomaly observed in Experiment 1 was not linked to the nature of the languages. However, the main effect of Order remained ($F_{(1,24)}$=19.43, p<.001): when participants performed the test for the second language, the percentage of correct answers increased significantly (S1C; ANOVA: S2C). For the IT, there were no significant main effects nor interactions (S1D; ANOVA: S2D) but, again, there was a general trend to increase the hit rate in the second language: similarly as in Experiment 1, nearly half of the subjects had also focused on the whole sentence during the learning phase of the second language, and this was actually reflected in a better performance.

Overall hit rates were analogous to the ones in experiment one: the means of the hit rates for the ET were between 70-85%, whereas the means for the IT were between 59-65% (Fig. 1). These results further support the conclusions drawn from Experiment 1, that is, that the rule embedded in the language was too difficult to be learned. Again, most of the participants rated the task with a difficulty level of 7 or 8 (only one participant rated it with a 9 and another with a 6; mean=7.64), and none of them had detected any rule or pattern related with the grammar upon which the Languages were created.

Pooled analyses of Experiments 1 and 2. For each Language and Test (ET and IT) unpaired *t*-tests were performed between the hit rates of Experiment 1 and 2, in order to check that they were similar. Actually, the results showed no significant differences between the hit rates of both Experiments (Fig. 1; *t*-tests: S3A-B).

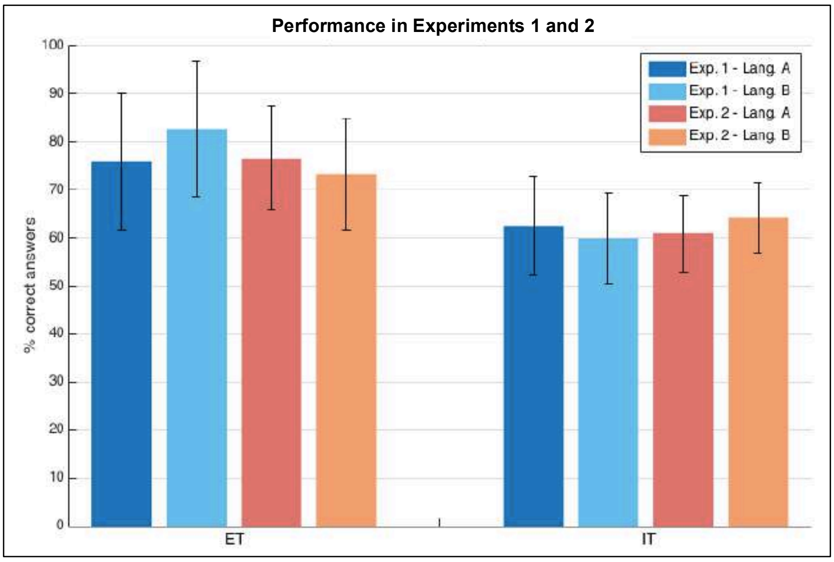


Fig. 1. Mean±SD of the % of correct answers for all the participants of each experiment.

3.2.2. ERPs results

Learning phase. The P200 modulation was analysed on frontal and fronto-central electrodes (AF3, AF4, F3, F1, Fz, F2, F4, FC5, FC3, FC1, FC2, FC4, FC6) within the 150-220 ms window. We did not observe an effect on the P200 component linked to explicit learning (S4). Since this ERP is time-locked to the beginning of the last long word of each sentence (i.e. where the participants had to focus) and the sentences had different length along the trials, this probably hindered the prediction of when the sentence would exactly end and of what would appear next. Thus, this section will be focused on the P200 linked to implicit learning (i.e. time-locked to the beginning of the first long word of each sentence). An ANOVA with factors Block, Language and Order revealed, as expected, a main effect of Block ($F_{(2,72)}$=3.26, p<.05) but also an interaction between Language and Order ($F_{(1,72)}$=5.68, p<.05; S5A-B): while P200 amplitude increased from first to second position in Language A, it slightly decreased in Language B. However, in order to increase statistical power, factors Language and Order were removed and paired *t*-tests between Blocks showed that P200 amplitude in Block 3 was higher than in Block 1 ($t_{(27)}$=-1.02, p<.001) and Block 2 ($t_{(27)}$=-3.12, p.<01), but amplitude in Block 2 was not higher than in Block 1 (Fig. 2; *t*-tests: S5C). Indeed, this gradual increase of P200 amplitude through blocks probably reflects the evolution of the acquisition process, which would be in line with previous findings (De Diego *et al.*, 2007).

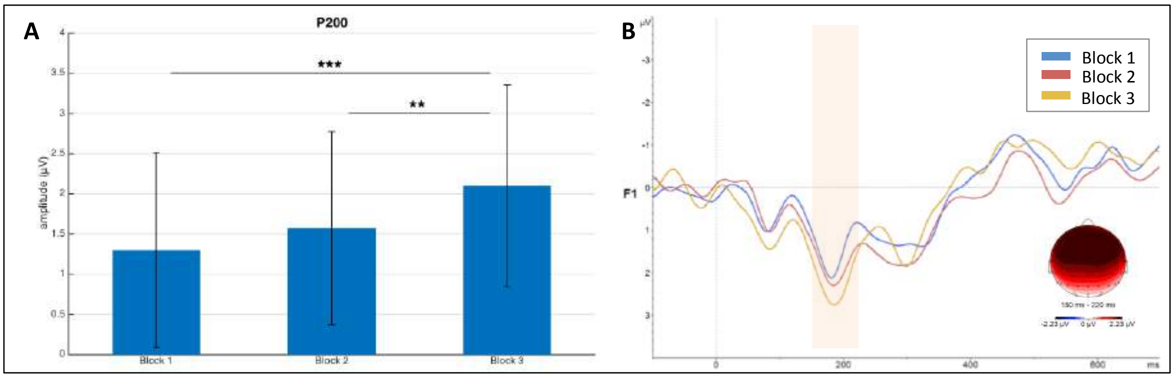


Fig. 2. A) Mean±SD of P200 amplitude for the considered frontal and fronto-central electrodes and all the participants of Experiment 2, for each Block. B) Grand-average ERPs at frontal (F1) electrode location comparing the 3 Blocks of the LP. The topography shows a central and frontal scalp distribution. Asterisks signify significant difference from chance level at p<.05 (*), p<.01 (**) and p<.001 (***).

Explicit-learning test. The P300 was analysed in parietal and occipital electrodes (P7, P5, P3, P1, Pz, P2, P4, P6, PO3, POz, PO4, PO9, O1, Oz, O2, PO10) within the 290-350 ms window; the N400 was analysed on central and frontal electrodes (AF3, AF4, F3, F1, Fz, F2, F4, FC5, FC3, FC1, FC2, FC4, FC6, C3, C1, Cz, C2, C4, P5, P3, P1, Pz, P2, P4, P6) within the 350-850 ms window. An ANOVA with factors Word, Language and Order showed that, contrary to what was expected, both in the P300 and N400 neither main effects nor interactions were significant (S6A, S7A). In order to increase statistical power, factors Language and Order were removed. The subsequent paired *t*-tests with the factor Word revealed that the amplitude of the P300 was higher in Words relative to Non-words ($t_{(27)}$=2.16, p.<05; Fig. 3A-B; *t*-tests: S6B): according to other evidence this finding reflects that participants correctly identified the target (i.e. words; Duncan-Johnson *et al.*, 1977; Katayama & Polich, 1998) and, thus, that they had explicitly learnt and memorised it. However, the same paired *t*-test for the N400 did not reveal a modulation of this component between Words and Non-words (Fig. 3C-D; *t*-tests: S7B), even though there was a slight tendency for Non-words to elicit higher N400 amplitude relative to Words. It could be that the actual design of the test hindered the N400 effect, since it required having in mind the first presented option until the second option appeared; besides, it could be that the two presented options were not different enough to be distinguished, which would be in line with previous studies (Curran, 2000).

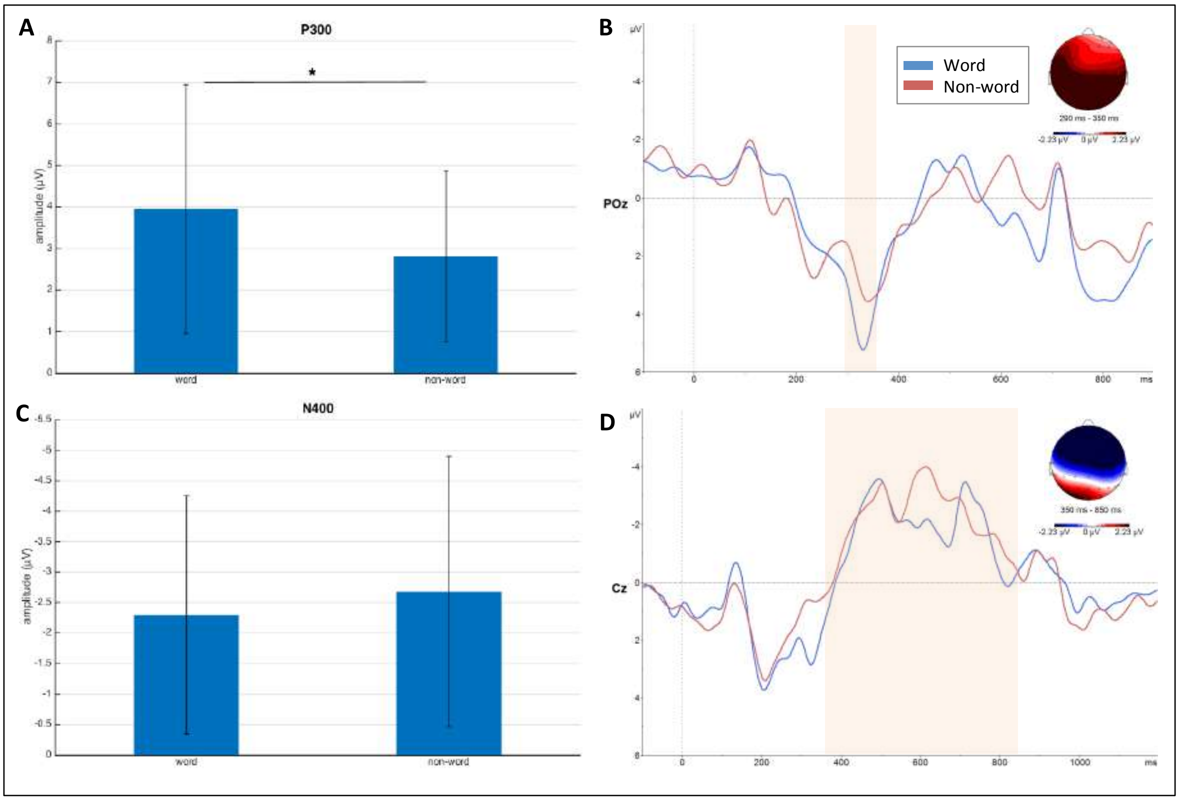


Fig. 3. A) Mean±SD of P300 amplitude for the considered parietal and occipital electrodes and for all the participants of Experiment 2, for both Words and Non-words. B) Grand-average ERPs at parieto-occipital (POz) electrode location comparing Word vs. Non-word. The topography shows a central and posterior scalp distribution. C) Mean±SD of N400 amplitude for the considered central and frontal electrodes and for all the participants of Experiment 2, for both Words and Non-words. D) Grand-average ERPs at central (Cz) electrode location comparing Word vs. Non-word. The topography shows a central and frontal scalp distribution. Asterisks signify significant difference from chance level at p<.05 (*), p<.01 (**) and p<.001 (***).

Implicit-learning test. The P600 was analysed on parietal and centro-parietal electrodes (CP5, CP3, CP1, CPz, CP2, CP4, CP6) within the 500-800 ms window. Similarly as happened with the P200 linked to explicit learning, the signal linked with the IT did not reveal the expected P600 component (S8), so it was decided not to perform further analyses, and no discussion will be made upon these results.

3.3. EXPERIMENT 3

3.3.1. Behavioural results

In Experiment 3, factor Language was blocked with Hierarchy, so that Language A matched High hierarchy and Language B matched Low hierarchy.

First, in a previous analysis it was checked that there was no interaction between Hierarchy and Order in the ET. The ANOVA confirmed this, and it was observed that hit rates followed the same pattern as in Experiment 2 (S9A-B): these results further supported that the anomaly observed in Experiment 1 was not linked to the nature of the languages, but rather to some outlier within the small sample of participants. Crucially, this ANOVA also revealed a main effect of Hierarchy ($F_{(1,52)}$=7.88, p<.01; S9A-B): the performance under the High hierarchy context was better than under the Low hierarchy context.

Second, it was tested the effect of Hierarchy and Actress. The factor Actress was introduced in order to control for any possible effect of the interpretation of the actresses in the social videos. Besides, in order to increase the statistical power it was decided to remove the factor Order because previous analyses had shown that it had no unexpected effect. The subsequent ANOVAs with the factors Hierarchy and Actress showed that, for the ET, there was a main effect of Hierarchy ($F_{(1,52)}$=9.17, p<.01), but also a significant interaction between Hierarchy and Actress ($F_{(1,52)}$=6.89, p<.05; S10 and S11A): despite for both actresses there was a tendency to decrease the hit rate from High to Low hierarchy, the magnitude of the decrease was greater for Actress 1 when compared to Actress 2. Probably, the interpretation of Actress 1 was more credible and convincing than the interpretation of Actress 2, thus enhancing the effect of the Hierarchy. For the IT, there was no significant effect (S11B).

Third, it was analysed the difficulty of the tests for each hierarchy. For the ET, the mean of the hit rate was expected to be higher for the High hierarchy than for the Low Hierarchy. For the IT no differences were expected under either of the social contexts. In order to increase the statistical power, factor Actress was removed and paired *t*-tests between High and Low hierarchy were performed for both the ET and IT. Actually, the results supported these predictions (Fig. 4): they showed that, for the ET, the hit rate under a High hierarchy context was significantly higher than under a Low hierarchy context ($t_{(27)}$=3.43, p<.01), whereas they had no effect on the IT (S12).

Regarding the three questions asked after the task, the answers from the participants were similar to those obtained in Experiments 1 and 2: all of the participants rated the task with a level of difficulty between 6 and 8 (mean=7.43); besides, all the participants had only focused on the last word of each sentence during the learning phase of the first language, and some of them focused on the whole sentence during the learning phase of the second language; finally, none of the participants detected any rule or pattern related with the grammar upon which the languages were created.

Pooled analyses of Experiments 2 and 3. For each Test (ET and IT) unpaired *t*-tests were performed between hit rates of Experiment 2 and 3, in order to compare each Hierarchy condition with its control pair (High hierarchy vs. Language A, and Low hierarchy vs. Language B).

The results revealed that there were no significant differences between the hit rates of both Experiments in neither of the Tests (Fig. 4; *t*-tests: S13A-B).

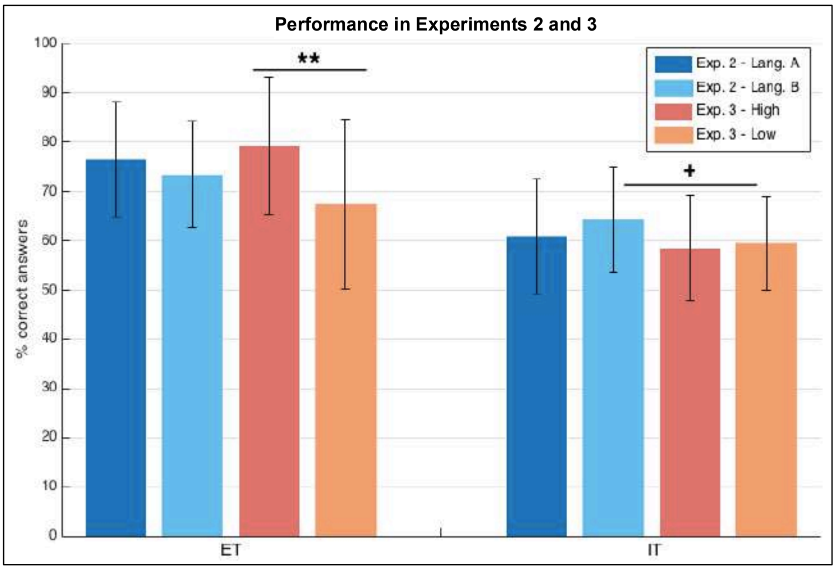


Fig. 4. Mean±SD of the % of correct answers for all the participants of each experiment. Asterisks signify significant difference from chance level at p<.05 (*), p<.01 (**) and p<.001 (***); cross signifies p<.1 (+).

3.3.2. ERPs results

Learning phase. The P200 modulation was analysed on frontal and fronto-central electrodes (AF3, AF4, F3, F1, Fz, F2, F4, FC5, FC3, FC1, FC2, FC4, FC6) within the 150-220 ms window. Similarly to Experiment 2, the ERPs related with explicit learning did not reveal a P200 component (S14A-B), so this section will be focused on the P200 linked to implicit learning. An ANOVA with factors Block, Hierarchy and Actress did not reveal any effect or interaction (S15A). In order to increase statistical power, factor Actress was removed. Thus, paired *t*-tests between Blocks showed that, for the High hierarchy, P200 amplitude in Block 2 was significantly higher than in Block 1 ($t_{(27)}$=-2.18, p<.05; Fig. 5A-B; *t*-tests: S15B), whereas for the Low hierarchy P200 amplitude in Block 3 was significantly higher than in Block 1 ($t_{(27)}$=-3.25, p<.01) and Block 2 ($t_{(27)}$=-2.78, p<.01; Fig. 5A,C; *t*-tests: S15C). Then, paired *t*-tests between Hierarchies were performed for each Block: only Block 2 was significantly higher in the High hierarchy relative to the Low hierarchy ($t_{(27)}$=1.83, p<.05; Fig. 5A; *t*-tests: S15D).

Pooled analyses of Experiments 2 and 3. Unpaired *t*-tests between each Hierarchy condition and its control pair showed no significant differences (Fig. 5A; *t*-tests: S15E-F). Fig. 5A also shows significant differences between Blocks for each of the control Languages (*t*-tests: S15G-H). Images of the ERPs for each Block between Language A and High hierarchy, and Language B and Low hierarchy can be found in S16.

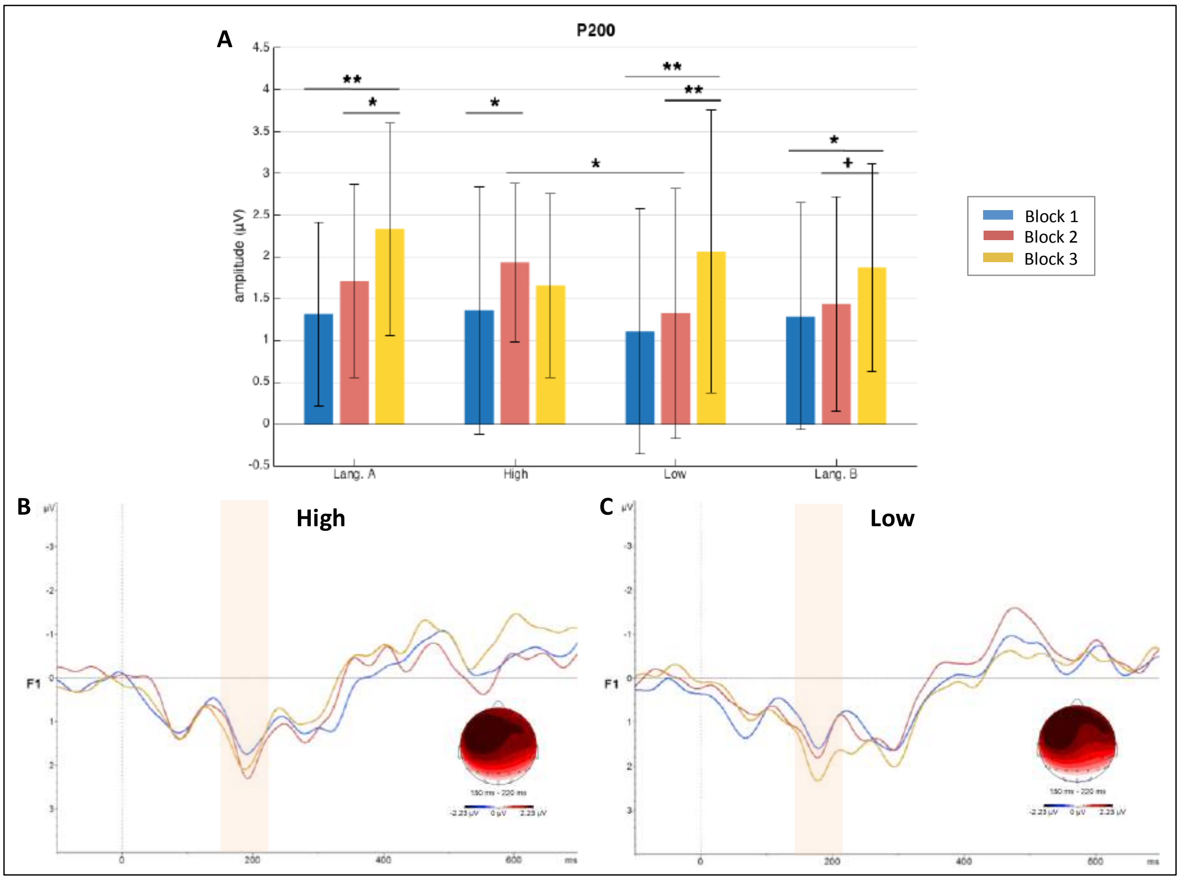


Fig. 5. A) Mean±SD of P200 amplitude for the considered frontal and fronto-central electrodes and all the participants of Experiment 2 and 3 respectively, for each Block. B) Grand-average ERPs at frontal (F1) electrode location comparing the 3 Blocks of the LP for the High hierarchy. The topography shows a central and frontal scalp distribution, slightly left lateralized. C) Same for the Low hierarchy. Asterisks signify significant difference from chance level at p<.05 (*), p<.01 (**) and p<.001 (***); cross signifies p<.1 (+).

Explicit-learning test. The P300 was analysed in parietal and occipital electrodes (P7, P5, P3, P1, Pz, P2, P4, P6, PO3, POz, PO4, PO9, O1, Oz, O2, PO10) within the 290-350 ms window; the N400 was analysed on central and frontal electrodes (AF3, AF4, F3, F1, Fz, F2, F4, FC5, FC3, FC1, FC2, FC4, FC6, C3, C1, Cz, C2, C4, P5, P3, P1, Pz, P2, P4, P6) within the 350-850 ms window. An ANOVA with factors Word, Hierarchy and Actress revealed, for both the P300 and N400, a main effect of Word (P300: $F_{(1,104)}=3.21$, $p<.05$; N400: $F_{(1,104)}=4.99$, $p<.05$; ANOVAs: S17A, S18A). In order to increase statistical power, factor Actress was removed. Paired *t*-tests between Word and Non-word were performed for each component and Hierarchy. Contrary to expected, the P300 amplitude for Words was not greater than for Non-words in the High hierarchy condition, but it was in the Low hierarchy condition ($t_{(27)}=3.56$, $p<.001$; Fig. 6A-C; *t*-tests: S17B-C). For the N400, its amplitude for Non-words was significantly higher in the High hierarchy condition (as expected), but also in the Low hierarchy conditions (High: $t_{(27)}=2.18$, $p<.05$; Low: $t_{(27)}=2.44$, $p<.05$; Fig. 7A-C; *t*-tests: S18B-C). Then, paired *t*-tests between Hierarchies were performed for Words and Non-words, but there were no significant differences neither for the P300 (Fig. 6A; *t*-tests: S17D) nor for the N400 (Fig. 7A; *t*-tests: S18D).

Pooled analyses of Experiments 2 and 3. Unpaired *t*-tests between each Hierarchy condition and its control pair were performed. For the P300, there were significant differences in both Words and Non-Words for the Language A / High hierarchy pair (Words: $t_{(40)}$=3.46, p<.01; Non-words: $t_{(40)}$=2.13, p<.05; Fig. 6A; *t*-tests: S17E), but there were only significant differences in Non-Words for the Language B / Low hierarchy pair ($t_{(40)}$=2.28, p<.05; Fig. 6A; *t*-tests: S17F). For the N400, there were no significant differences in neither of the pairs (Fig. 7A; *t*-tests: S18E-F). Significant differences between Word and Non-word for each of the control Languages are shown in Fig. 6A (P300) and 7A (N400) (*t*-tests: P300: S17G-H; N400: S18G-H). Images of the ERPs for Word and Non-word, between Language A and High hierarchy, and Language B and Low hierarchy, can be found in S19 (P300) and S20 (N400).

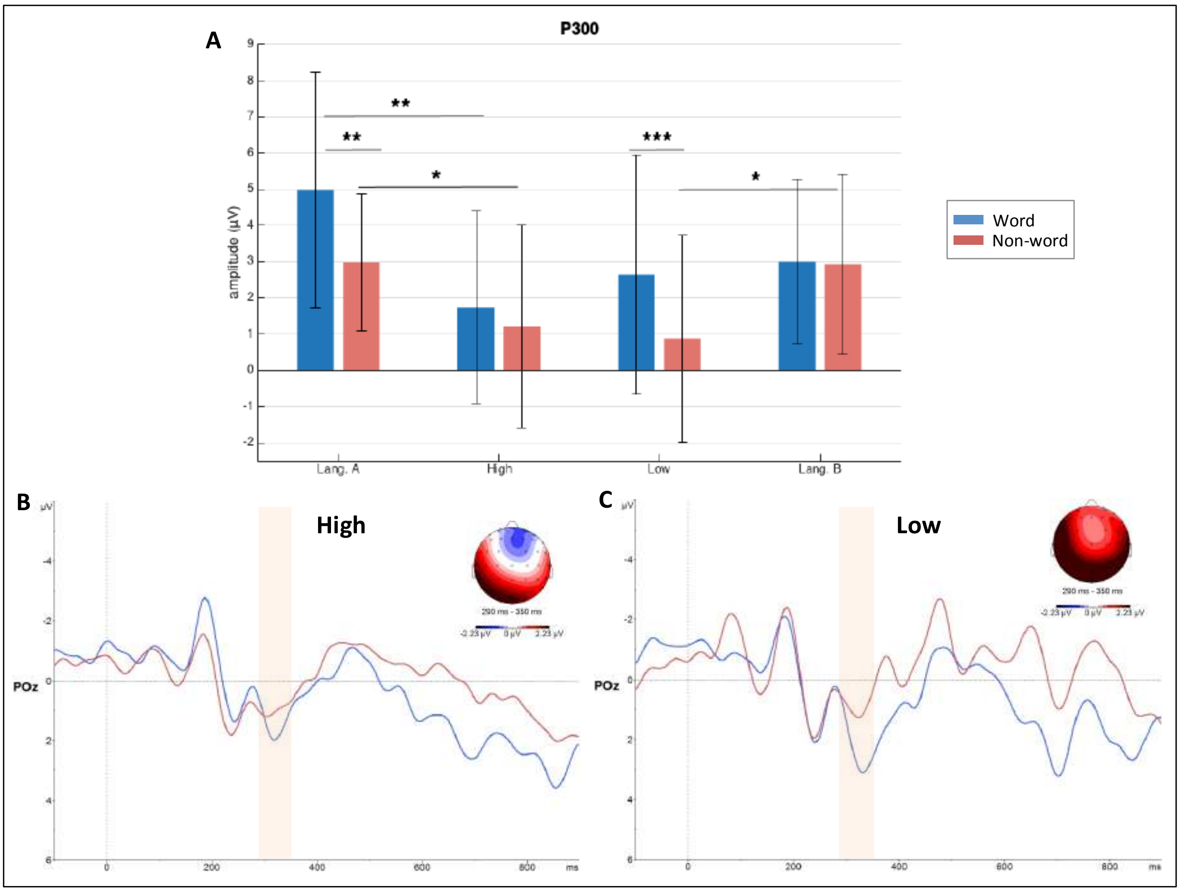


Fig. 6. A) Mean±SD of P300 amplitude for the considered parietal and occipital electrodes and for all the participants of Experiment 2 and 3 respectively, for both Words and Non-words. B) Grand-average ERPs at parieto-occipital (POz) electrode location comparing Word vs. Non-word for the High hierarchy. The topography shows a posterior scalp distribution. C) Same for the for the Low hierarchy. Here the topography shows a posterior and temporal scalp distribution. Asterisks signify significant difference from chance level at p<.05 (*), p<.01 (**) and p<.001 (***).

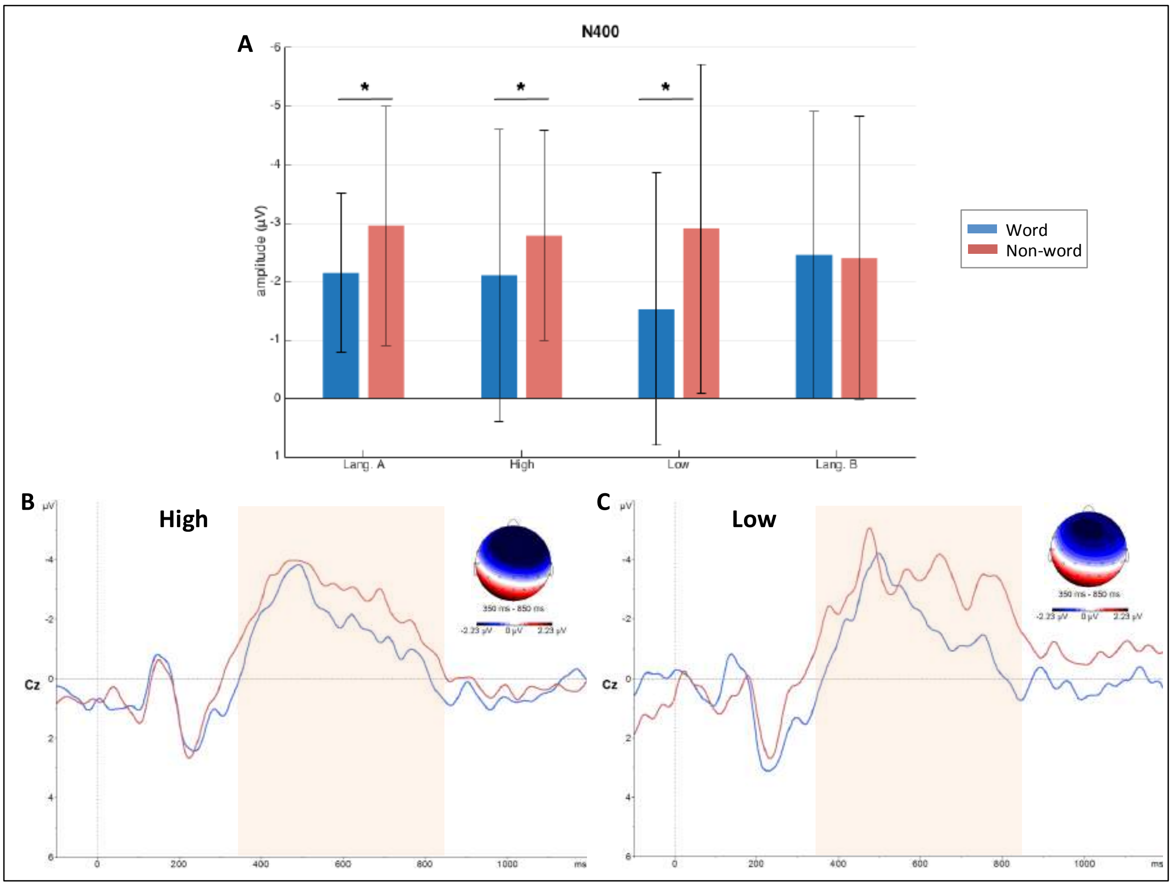


Fig. 7. A) Mean±SD of N400 amplitude for the considered central and frontal electrodes and for all the participants of Experiment 2 and 3 respectively, for both Words and Non-words. B) Grand-average ERPs at central (Cz) electrode location comparing Word vs. Non-word for the High hierarchy. The topography shows a fronto-central scalp distribution. C) Same for the Low hierarchy. Asterisks signify significant difference from chance level at p<.05 (*), p<.01 (**) and p<.001 (***).

Implicit-learning test. The P600 was analysed on parietal and centro-parietal electrodes (CP5, CP3, CP1, CPz, CP2, CP4, CP6) within the 500-800 ms window. Similarly as in Experiment 2, the signal linked with the IT did not reveal the expected P600 component for neither of the Hierarchies (S21), so it was also decided not to perform further analyses, and no discussion will be made upon these results.

4. DISCUSSION

The aim of the present study was to contribute to the body of research on how social factors influence learning, but from a neurocognitive perspective. Particularly, it was analysed how social hierarchies influence implicit and explicit learning, and to what extent the effect differs between high and low hierarchy. Given that previous evidence shows that high social hierarchies attract more attention than low social hierarchies (Chiao *et al.*, 2008; Santamaría-García *et al.*, 2013a; Zink *et al.*, 2008), and that the impact of attention is greater for explicit learning than for implicit learning, we expected that the greatest changes would be found in explicit learning under the high hierarchy context. However, some of the results challenge our hypothesis: overall, taking together the behavioural and electrophysiological findings, the results suggest that the rank to which the speaker belongs has an effect both on explicit and implicit learning.

On the one hand, the effect on explicit learning is mainly reflected in the performance of the participants in the explicit-learning test (ET), where an individual performs better or worse depending on who he interacts to. Actually, when the hit rates between the two hierarchies are compared, the percentage of correct answers for the High rank is significantly higher than for the Low rank: despite neither of the Hierarchy conditions was significantly different from its control pair, the former is in the upper end of the range set in the control condition, whereas the latter is below the lower end. According to the theories of Festinger and Sears (Festinger, 1954; Sears, 1940), this finding shows evidence that participants adjust their level of aspiration to that of their speaker, so that it is increased or decreased in a high or low rank environment, respectively. Besides, it shows that explicit learning highly depends on attention, since both hierarchical contexts have an effect on the performance; this is in line with previous experiments showing similar effects (Santamaría-García *et al.*, 2013a).

Unfortunately, the ERPs results do not allow to take straightforward conclusions about the influence of social hierarchies on the neurophysiological basis of explicit learning. First, regarding the P300, despite the analyses in Experiment 2 show that both languages have similar P300 amplitude for Words and Non-words, the posterior analyses of each Language show that Language B does not elicit different P300 amplitude between Words and Non-words. Moreover, for the High hierarchy condition the P300 amplitude is significantly lower than in its control pair for both Words and Non-words, and within the own condition there are no differences between them (even though there is a tendency for Words to have higher amplitude than Non-words). One possibility is that, as in this context participants wanted to perform better, they are equally attentive to both options, and this is reflected in a reduction of the difference in amplitude between Words and Non-words. Conversely, for the Low hierarchy condition the P300 amplitude for Non-words significantly drops when compared to its control pair and, contrary to what was expected, appears a drastically enhanced modulation of this component. Given that no modulation was seen in its control pair, this probably reflects a powerful “person effect” within the hierarchical context. Second, regarding the N400, a similar scenario to that of the P300 emerges: again, when dissociating the analyses for each of the Languages within the control condition, Language B shows no difference in the N400 amplitude elicited by Words and Non-words, while in the Low hierarchy condition a “person effect” appears again: this rules out the explanation suggested in Experiment 2, posing that the absence of N400 modulation was due to the design of the test or too much similarity between the two options. Furthermore, no differences between Hierarchies or between each Hierarchy condition and its control pair were found, which for the moment excludes any influence of the hierarchical context on this component. Globally, the unexpected findings in the P300 and N400 components do not allow to draw a clear picture of the influence of the Hierarchy context on the neural processes that underlie explicit learning, at least for the moment.

On the other hand, the Hierarchy context does not have any effect on the performance in the implicit-learning test, as the hit rates do not differ between High and Low hierarchy, nor between the ones obtained in the control experiment (Experiment 2): all of them show a “slightly-above-chance” performance. However, since participants do not show clear learning of the implicit rule already in the control condition, it cannot be concluded that the lack of influence of the hierarchical social context results either from the low impact of attention on implicit learning (which would be in line with our hypothesis), or because the implicit rule was too difficult to learn under any condition.

Luckily, the ERPs findings are more clarifying about the influence of social hierarchies on implicit learning. For the control condition, the P200 linked to implicit learning (recorded during the learning phase) shows that its amplitude gradually increases through blocks, and that the greatest changes appear in Block 3, where P200 amplitude is significantly higher than in Blocks 1 and 2. While the Low hierarchy condition shows the same pattern as the control, in the High hierarchy condition a new pattern emerges: here, the maximum amplitude of P200 is found in Block 2, which is significantly higher than the amplitude in Block 1 and than the amplitude of Block 2 in the Low hierarchy condition. Interestingly, the study of De Diego *et al.* (where the learning phase had four blocks instead of three) reported that P200 amplitude increased from Block 1 to 3, but then it decreased from Block 3 to 4. Thus, the present results could be a reflection of participants learning “faster” in the High hierarchy condition, that is, the amplitude associated to Block 3 in the control condition would correspond to Block 2, and the amplitude that would have been associated to Block 4 in the control condition would correspond to Block 3.

Therefore, contrary to what was expected, the presence of a High hierarchy speaker does have an effect on implicit learning, at least neurophysiologically: this effect probably emerges from a the higher level of attention payed to the High rank speaker together with the increase of the level of aspiration. Crucially, the effect is not reflected as greater amplitude of P200 in each block, but rather as an acceleration of the acquisition process. This result suggests that the lack of influence of the social hierarchies on the performance in the IT is due to the implicit rule being too difficult to learn, so that if the level of difficulty was decreased, an effect on the behavioural results might be found.

Taking into account the present results, together with the early work of Festinger and Sears and the latest neuroanatomical studies, it is not surprising that, in 2012, PISA (Programme for International Student Assessment) reported that the countries with better student outcomes were the ones where teachers are given top priority in training, professionalism, remuneration and, crucially, social respect (Chambi, 2014). It also reported that these countries put more emphasis on the selection of teachers, that is, in order for a person to become an efficient teacher, he must have "high level of general knowledge in languages and arithmetic, strong interpersonal and communicative skills, willingness to learn and motivation to teach" (EFE, 2013). This evidence suggests that one of the main drivers for the variation in student learning at school is the quality of the teachers. Actually, this has been shown by several studies; for instance, Barber and colleagues showed that students placed with high performing teachers progressed three times faster than those placed with low performing teachers, and that having a low performing teacher during primary school entailed an educational loss that was largely irreversible (Barber & Mourshed, 2007; other related studies: Jordan *et al.*, 1997; Peske & Haycock, 2006; Sanders & Rivers, 1996). One possibility is that, since being perceived as a higher or lower rank can make a person (e.g. teacher) more or less reliable (Santamaría-García *et al.*, 2013b), this might foster or not an upward comparison and aim of self-improvement that, as shown in the present study, would in turn enhance or undermine learning. Overall, this sets a great challenge regarding the role of the teacher within our society and educational systems.

Finally, I want to emphasize that these results are a preliminary analysis of the data collected throughout the three experiments. Thus, the conclusions that are drawn from them should not be considered as ultimate, but rather a first promising step upon which continue subsequent work.

5. CONCLUSIONS AND FURTHER RESEARCH

In conclusion, the present results suggest that under a social hierarchy context, both explicit and implicit learning are influenced. While on explicit learning this effect is reflected overtly in the behavioural task, the influence on implicit learning is hidden in changes on the neural physiology that underlies this process. This evidence is in line with the level of aspiration theory, which postulates that the aim of self-improvement is modified depending on the rank of the speaker (Festinger, 1954): here, we show that this causes changes not only on the behaviour, but also at the neural level. However, the high difficulty in the implicit rule and the controverted electrophysiological results do not allow to draw clear conclusions of how they are influenced. We cannot conclude that they are not affected by the hierarchical environment, but rather suggest new ways to unravel the effect.

First, some improvements on the experimental design should be born in mind. One limitation of this study was that, from the very first experiment, the performance of the participants in the implicit-learning test showed that the implicit rule was too difficult to be learnt (the hit rate was near chance), and this hinders any attempt to assess the effect of the social hierarchies on it. Thus, it is necessary to modify the implicit rule so that already in the control condition the hit rate reflects that participants do learn the rule. Another limitation was that, due to the lack of time to collect data from a sufficiently large number of participants, only half of the social hierarchy conditions were tested, since the factor Language was blocked with Hierarchy. Thus, in subsequent experiments we will test how the scenario changes (or not) when the Language A matches Low hierarchy, and Language B matches High hierarchy. Besides, the effect of the hierarchies could be strengthened by adding a game between the presentation of the speaker and the task itself: the outcome of the game should be rigged such that under the high hierarchy condition the speaker wins more often, but under the low hierarchy condition he loses more often; other studies have already proved the efficiency of this trick (Santamaría-García *et al.*, 2013a,b). Moreover, the size of the samples should be increased: since the variability in the electrophysiological signal is much higher than in the behavioural performance, increasing the statistical power can help bringing out clearer patterns between conditions.

Second, more in-depth analyses of the data should be performed. For instance, participants could be divided in good and bad learners: when De Diego *et al.* did so in their study (De Diego *et al.*, 2007), they found different modulation in the P200 and N400 for each group. Besides, here we only analysed amplitude modulation but, possibly, changes in latency could also help to unfold other kinds of modulations due to the social hierarchy context. Furthermore, given that attention is the underlying platform upon which hierarchies have their effect, and whose impact differently influences explicit and implicit learning, it would be interesting to analyse attention-related ERP components that have been previously reported to change under different social hierarchy context; one example would be the N1 (Santamaría-García *et al.*, 2013a).

Finally, I would like to highlight how much I have learnt throughout this project. From the first steps of creating the materials and programming the task, up to the execution of the electrophysiological experiments and posterior data processing and analyses, together with the reasoning process behind each new step, during this complex study I have acquired many new skills that, for sure, will be very useful for my future research career.

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7. ANNEXES

7.1. ABBREVIATIONS

ANOVA	Analysis of Variance
EEG	Electroencephalogram
ERPs	Event-Related Potentials
ET	Explicit-learning Test
Hz	Hertz
IT	Implicit-learning Test
kOhm	kiloOhms
LP	Learning phase
ms	milliseconds
SD	Standard Deviation
t-test	Student’s *t*-test

7.2. MATERIALS

7.2.1. Artificial languages

Table A. Examples of noun phrases and sentences of language A.

2 noun phrases	B *ji*	2 *kalu*	D *fo*	1 *tirre*						
3 noun phrases	B *ji*	2 *kalu*	A *pu*	2 *lemo*	A *ko*	1 *tirre*				
3 noun phrases	B *ne*	2 *lemo*	D *ga*	1 *tirre*	C *mu*	2 *guison*				
4 noun phrases	B *ji*	2 *guison*	A *ko*	2 *niba*	A *pu*	1 *erpo*	C *mu*	2 *lemo*		
4 noun phrases	B *ne*	2 *niba*	D *fo*	1 *fusa*	C *mu*	2 *lemo*	D *ga*	2 *kalu*		
5 noun phrases	B *ne*	2 *lemo*	A *pu*	2 *gison*	A *ko*	1 *erpo*	C *rra*	2 *kalu*	D *ga*	2 *fedu*

Table B. Short words and long words of Language B (the rules used to form noun phrases and sentences were the same as in Language A).

Short words				Long words	
A	B	C	D	1	2
je	ta	ku	so	arlo	bipe
go	di	na	ju	togue	gura
				keri	suña
				imbu	firo
					rrotu
					mabe

Table C. Examples of noun phrases and sentences of Language B.

2 noun phrases	B *ta*	2 *bipe*	D *so*	1 *arlo*						
3 noun phrases	B *di*	2 *bipe*	A *go*	2 *suña*	A *go*	1 *imbu*				
	B *di*	2 *suña*	D *so*	1 *togue*	C *na*	2 *firo*				
4 noun phrases	B *di*	2 *bipe*	A *go*	2 *suña*	A *je*	1 *arlo*	C *na*	2 *gura*		
	B *ta*	2 *suña*	D *so*	1 *togue*	C *ku*	2 *rrotu*	D *ju*	2 *firo*		
5 noun phrases	B *ta*	2 *gura*	A *go*	2 *suña*	A *go*	1 *imbu*	C *na*	2 *firo*	D *ju*	2 *bipe*

Table D. Word violations for language A. To help explain word violations, each noun phrase will be divided in three syllables "a-b-c", being "b-c" the syllables corresponding to the long word, and therefore the ones on which the violation was applied. The syllables "d-e-f" match any other noun phrase of the language, from which syllables could be taken to create the violation of "b-c".

Noun phrase	Word	Type of Non-word	
… a - b-c *… fo danu*	b-c *danu*	**1**	a-c *fonu*
… a - b-c *… rra lemo*	b-c *lemo*	**2**	d-c *pumo*
… a - b-c *… fo fusa*	b-c *fusa*	**3**	c-f *sañi*
… a - b-c *… rra niba*	b-c *niba*	**4**	b-a *nirra*

Table E. Rule sentence violations for Language A. To help explain sentence violations, each target noun phrase will be divided in three syllables "a-b-c". The syllables "d-e-f" match any other noun phrase of the sentence, from which syllables could be taken to create the violation in "a-b-c". Violations never took place in the first noun phrase: for all kind of sentences violation took place either in the second or third noun phrase.

Sentence	Rule	Type of Non-rule	
… d - e-f -[…]- a - b-c … *… ji kalu - fo tirre …*	a - b-c *fo tirre*	**1**	b - c-a *ti rrefo*
… d - e-f -[…]- a - b-c … *… ne doñi - ga fusa …*	a - b-c *ga fusa*	**2**	e - b-c *do fusa*
… d - e-f -[…]- a - b-c … *… ne lemo - ga danu …*	a-b-c *ga danu*	**3**	d - a-c *ne ganu*

<u>Table F.</u> Word violations for Language B. To help explain word violations, each noun phrase will be divided in three syllables "a-b-c", being "b-c" the syllables corresponding to the long word, and therefore the ones on which the violation was applied. The syllables "d-e-f" match any other noun phrase of the language, from which syllables could be taken to create the violation of "b-c".

Noun phrase	Word	Type of Non-word	
… a - b-c *… na rrotu*	b-c *rrotu*	**1**	a-c *natu*
… a - b-c *… so keri*	b-c *keri*	**2**	d-c *nari*
… a - b-c *… ju mabe*	b-c *mabe*	**3**	c-f *bero*
… a - b-c *… ku suña*	b-c *suña*	**4**	b-a *suku*

<u>Table G.</u> Rule sentence violations for Language B. To help explain sentence violations, each target noun phrase will be divided in three syllables "a-b-c". The syllables "d-e-f" match any other noun phrase of the sentence, from which syllables could be taken to create the violation in "a-b-c". Violations never took place in the first noun phrase: for all kind of sentences violation took place either in the second or third noun phrase.

Sentence	Rule	Type of Non-rule	
… d - e-f -[…]- a - b-c … *… ta bipe - so arlo …*	a - b-c *so arlo*	**1**	b - c-a *ar loso*
… d - e-f -[…]- a - b-c … *… di gura - ju togue …*	a - b-c *ju togue*	**2**	e - b-c *gu togue*
… d - e-f -[…]- a - b-c … *… ju arlo - na suña …*	a-b-c *na suña*	**3**	d - a-c *ju naña*

7.2.2. Materials for Experiment 3

Box A. High hierarchy script.

¡Hola! Me llamo Marta. Soy de Madrid, pero estudié la carrera de Matemáticas y Ciencias Informáticas en Inglaterra. Después me trasladé a Barcelona para hacer un máster aquí, en la Universidad Pompeu Fabra, donde actualmente estoy haciendo el doctorado.

Voy a presentar mi tesis de aquí a dos meses, y después me iré a Estados Unidos una temporada porque me han dado una beca para hacer un post-doc allí. Realmente me apasiona lo que hago, y creo que esto es la clave para triunfar. A parte del trabajo, los fines de semana me gusta quedar con mis amigos y salir por las noches.

Me he apuntado a este experimento porque creo que poniendo cada uno su granito de arena es como la ciencia avanza.

Ahora me gustaría enseñarte un lenguaje secreto que mi hermana y yo nos inventamos cuando éramos pequeñas... Nos encantaba jugar a ser espías y que nadie más nos pudiera entender.

Para ver como de buena eres en aprender el lenguaje secreto, ¡vamos a jugar un poco! En primer lugar te voy a mostrar algunas frases del lenguaje secreto y quiero que memorices la última palabra de cada frase.

Me acuerdo que cuando mi hermana y yo nos inventábamos las palabras me acordaba de ellas muy fácilmente, ¡así que vamos a ver si puedes superarme! Acuérdate, pon atención a la última palabra de cada frase. Clica la barra espaciadora cuando estés preparada para empezar.

(Learning Phase)

Ahora vamos a comprobar si has sido capaz de memorizar más palabras que yo. Para esto, escucharás parejas de palabras, y deberás decidir cuál de las dos coincide con alguna que apareció última en alguna frase.

Si crees que la correcta es la primera palabra, clica la tecla 1. Si crees que la correcta es la segunda palabra, clica la tecla 2. Clica la barra espaciadora cuando estés preparada para empezar.

(Explicit-learning Test)

Si te has acordado de muchas palabras debes de ser realmente buena. Ahora lo comprobaremos de otra manera: escucharás parejas de frases, y luego tienes que decidir cuál de las dos ya la habías escuchado antes.

Si crees que la correcta es la primera frase, clica la tecla 1. Si crees que la correcta es la segunda frase, clica la tecla 2. Clica la barra espaciadora cuando estés preparada para empezar.

(Implicit-learning Test)

¡Muchas gracias por tu colaboración!

Box B. Low hierarchy script.

Hola, mi nombre es Vane y soy de Castellón. Empecé a estudiar Administración de Empresas en la Universidad de Barcelona pero dejé la carrera en segundo porque no me gustaba mucho, y entonces pasé una temporada sin hacer nada... Ahora trabajo como reponedora en el Carrefour de aquí delante, en el centro comercial de las Glorias.

El contrato se me acaba este mes pero espero que me lo renueven. Muchas veces tengo que hacer horas extra los sábados y eso me fastidia un poco porque los fines de semana me gusta salir con mis amigos por la noche, pero bueno, por el resto supongo que está bien, no sé.

Me he apuntado a este experimento porque una amiga me lo dijo y me pareció interesante, y a lo mejor puedo aprender algo... ah, y también por lo que pagan, claro.

Bueno, ahora quiero enseñarte un lenguaje que una amiga y yo utilizábamos en el cole cuando nos castigaban, porque así el profe no nos podía entender.

Para ver como de buena eres en aprender el lenguaje secreto vamos a hacer un juego... Primero te voy a mostrar algunas frases y quiero que intentes acordarte de la última palabra de cada una.

Me acuerdo que esto de memorizar tantas palabras era un poco difícil para mi... así que posiblemente me puedas superar fácilmente. Acuérdate, pon atención a la última palabra de cada frase. Clica la barra espaciadora cuando estés preparada para empezar.

(Learning Phase)

Es probable que tú hayas sido capaz de memorizar más palabras que yo... Vamos a comprobarlo de la siguiente manera: escucharás parejas de palabras, y deberás decidir cuál de las dos coincide con alguna que apareció última en alguna frase.

Si crees que la correcta es la primera palabra, clica la tecla 1. Si crees que la correcta es la segunda palabra, clica la tecla 2. Clica la barra espaciadora cuando estés preparada para empezar.

(Explicit-learning Test)

¿Cómo ha ido? Probablemente no lo hayas encontrado muy difícil... Bueno... Ahora lo comprobaremos de otra manera: escucharás parejas de frases, y luego tienes que decidir cuál de las dos ya la habías escuchado antes.

Si crees que la correcta es la primera frase, clica la tecla 1. Si crees que la correcta es la segunda frase, clica la tecla 2. Clica la barra espaciadora cuando estés preparada para empezar.

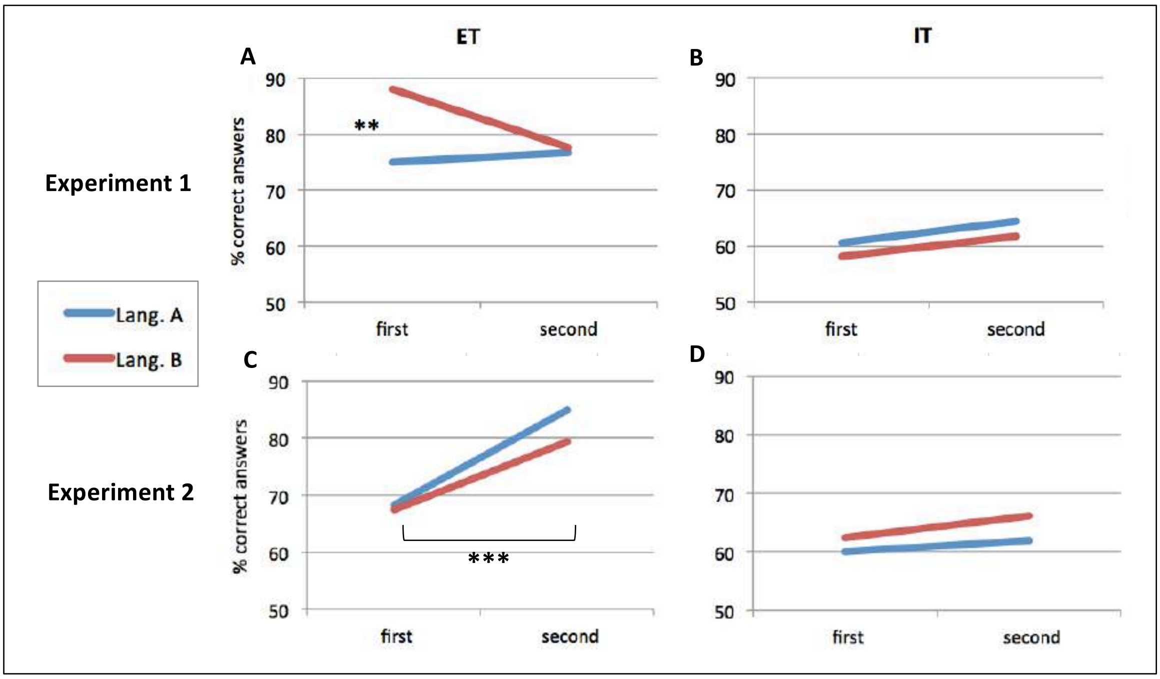
(Implicit-learning Test)

¡Muchas gracias por tu colaboración!

Box C. Phases of the experiment. A) Instructions for the LP. B) Screen displayed during the LP. C) Instructions for the ET. D) Screen displayed during the presentation of the two options in the ET and subsequent question. E) Instructions for the IT. F) Screen displayed during the presentation of the two options in the IT and subsequent question.

Box D. Pictures of all the characters.

7.3. SUPPLEMENTARY FIGURES



S1. Plot of the interaction Language - Order in Experiment 1 (A=ET; B=IT) and 2 (C=ET; D=IT). Asterisks signify significant difference from chance level at p<.05 (*), p<.01 (**) and p<.001 (***).

A

Source	Sum Sq.	d.f.	Mean Sq.	F	Prob>F
lang	6.78	1	6.78	0.05	0.8298
ord	903.07	1	903.07	6.31	0.0207
lang*ord	1180.76	1	1180.76	8.26	0.0094
Error	2860.28	20	143.01		
Total	4950.9	23			

B

Source	Sum Sq.	d.f.	Mean Sq.	F	Prob>F
lang	40.64	1	40.638	0.39	0.5378
ord	82.7	1	82.696	0.8	0.3818
lang*ord	0.19	1	0.186	0	0.9666
Error	2067.94	20	103.397		
Total	2191.46	23			

C

Source	Sum Sq.	d.f.	Mean Sq.	F	Prob>F
lang	70.56	1	70.56	0.96	0.3369
ord	1428.14	1	1428.14	19.43	0.0002
lang*ord	39.67	1	39.67	0.54	0.4696
Error	1763.65	24	73.49		
Total	3302.03	27			

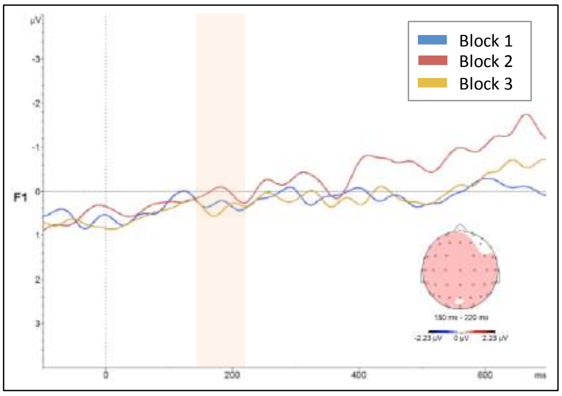
D

Source	Sum Sq.	d.f.	Mean Sq.	F	Prob>F
lang	77.72	1	77.7222	1.27	0.2706
ord	57.17	1	57.1714	0.94	0.3431
lang*ord	6.33	1	6.327	0.1	0.7504
Error	1466.59	24	61.1079		
Total	1607.81	27			

S2. ANOVAs of the interaction Language - Order in Experiment 1 (A=ET; B=IT) and 2 (C=ET; D=IT).

	Lang. A:	Lang. B:
A	p=0.8899 t-stat=-0.1399 df=24 sd=12.8479	p=0.0687 t-stat=1.9061 df=24 sd=12.4428
B	p=0.6585 t-stat=0.4475 df=24 sd=8.7948	p=0.2132 t-stat=-1.2788 df=24 sd=8.7191

S3. Unpaired *t*-test between Experiment 1 and 2, for ET (A) and IT (B).

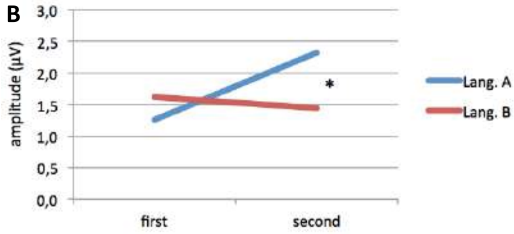


S4. Grand-average ERPs at frontal (F1) electrode location comparing the 3 Blocks of the LP; these ERPs were time-locked to the beginning of the last long word of each sentence, as a marker of explicit learning. The topography shows a slight global positivity in the scalp.

A

Source	Sum Sq.	d.f.	Mean Sq.	F	Prob>F
block	9.282	2	4.64091	3.26	0.044
lang	1.355	1	1.35514	0.95	0.3322
ord	4.052	1	4.05152	2.85	0.0957
block*lang	0.659	2	0.32947	0.23	0.7938
block*ord	1.817	2	0.90848	0.64	0.5308
lang*ord	8.071	1	8.07146	5.68	0.0198
block*lang*ord	3.144	2	1.57192	1.11	0.3366
Error	102.371	72	1.42182		
Total	130.751	83			

B



C

Block 1 - Block 2:
p=0.3150
t-stat=-1.0239
df=27
sd=1.0402

Block 1 - Block 3:
p=0.0002
t-stat=-4.3524
df=27
sd=0.9561

Block 2 - Block 3:
p=0.0043
t-stat=-3.1156
df=27
sd=0.9938

S5. A) ANOVA of the interaction Block - Language - Order for P200. B) Plot of the interaction Language - Order. C) Paired *t*-tests between Blocks.

A

Source	Sum Sq.	d.f.	Mean Sq.	F	Prob>F
word	14.926	1	14.9258	2.21	0.1436
lang	14.561	1	14.5606	2.16	0.1485
ord	0.06	1	0.0597	0.01	0.9255
word*lang	12.976	1	12.9758	1.92	0.1721
word*ord	0.099	1	0.0991	0.01	0.9041
lang*ord	6.634	1	6.6344	0.98	0.3265
word*lang*ord	0.21	1	0.2096	0.03	0.8609
Error	324.082	48	6.7517		
Total	373.547	55			

B

Word vs. non-word:
p=0.0199
t-stat=2.1610
df=27
sd=2.7664

S6. A) ANOVA of the interaction Word - Language - Order for P300. B) Paired *t*-tests between Word - Non-word.

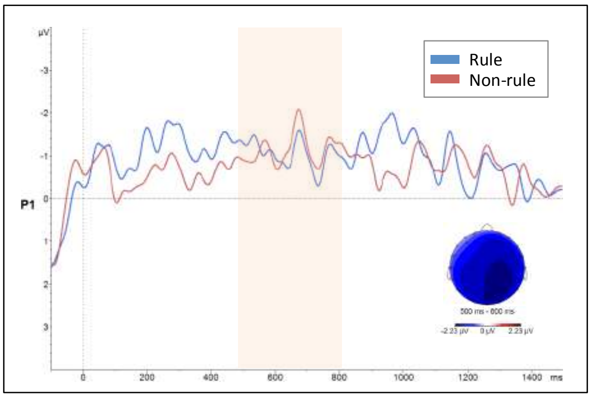
A

Source	Sum Sq.	d.f.	Mean Sq.	F	Prob>F
word	2.047	1	2.04718	0.43	0.5166
lang	0.21	1	0.21032	0.04	0.835
ord	1.218	1	1.21825	0.25	0.6165
word*lang	2.607	1	2.60676	0.54	0.4645
word*ord	0.06	1	0.05976	0.01	0.9116
lang*ord	0.441	1	0.44096	0.09	0.763
word*lang*ord	1.028	1	1.02817	0.21	0.6454
Error	230.132	48	4.79441		
Total	237.743	55			

B

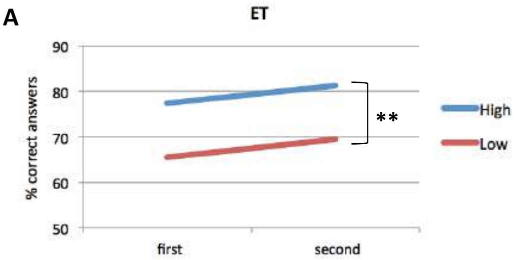
Word vs. non-word:
p=0.1632
t-stat=0.9997
df=27
sd=2.0240

S7. A) ANOVA of the interaction Word - Language - Order for N400. B) Paired *t*-tests between Word - Non-word.



S8. Grand-average ERPs at frontal (P1) electrode location comparing the Rule and Non-rule sentences. The topography shows a slight global negativity in the scalp.

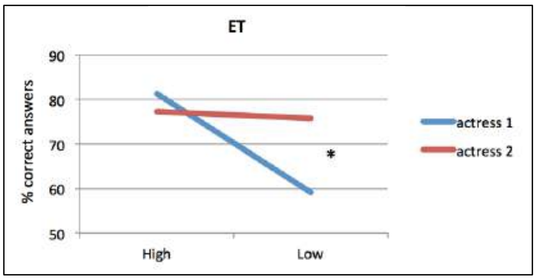
A



B

Source	Sum Sq.	d.f.	Mean Sq.	F	Prob>F
hier	1984.2	1	1984.21	7.88	0.007
order	220.3	1	220.26	0.88	0.3538
hier*order	0	1	0	0	0.9999
Error	13085.5	52	251.64		
Total	15289.9	55			

S9. A) Plot of the interaction Hierarchy (=Language) - Order for the ET. Asterisks signify significant difference from chance level at p<.05 (*), p<.01 (**) and p<.001 (***). B) ANOVA of the interaction Hierarchy (=Language) - Order for the ET.



S10. Plot of the interaction Hierarchy - Actress for the ET. Asterisks signify significant difference from chance level at p<.05 (*), p<.01 (**) and p<.001 (***).

A

Source	Sum Sq.	d.f.	Mean Sq.	F	Prob>F
hier	1984.2	1	1984.21	9.17	0.0038
actr	564.1	1	564.13	2.61	0.1124
hier*actr	1490	1	1490	6.89	0.0114
Error	11251.6	52	216.38		
Total	15289.9	55			

B

Source	Sum Sq.	d.f.	Mean Sq.	F	Prob>F
hier	12.92	1	12.922	0.12	0.7253
actr	63.82	1	63.815	0.62	0.436
hier*actr	63.82	1	63.815	0.62	0.436
Error	5383.58	52	103.53		
Total	5524.13	55			

S11. ANOVA of the interaction Hierarchy - Actress for the ET (A) and IT (B).

ET:
p=0.0010
t-stat=3.4281
df=27
sd=18.3761

IT:
p=0.6410
t-stat=-0.3651
df=27
sd=13.9251

S12. Paired *t*-test between High and Low hierarchy, for each test.

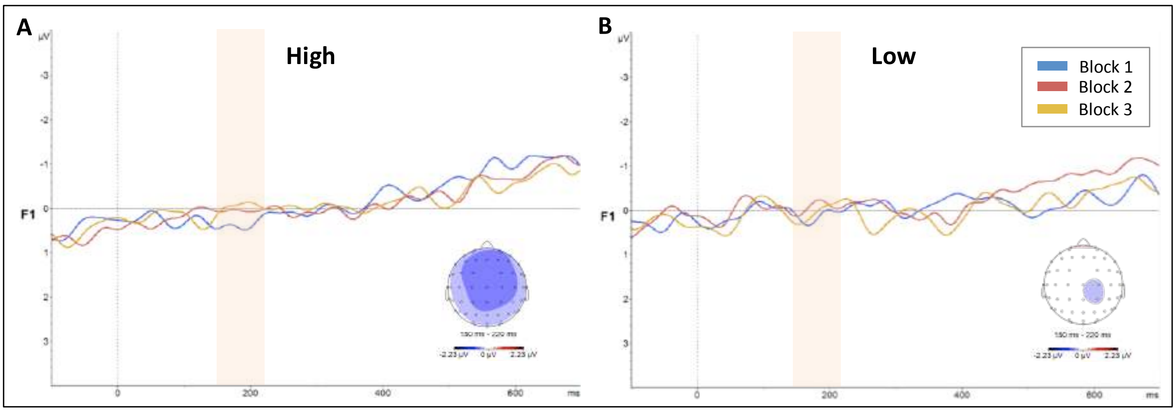
A
Lang. A - High:
p= 0.2629
t-stat=0.6401
df=40
sd=13.2657

Lang. B - Low:
p=0.1225
t-stat=-1.1798
df=40
sd=15.4094

B
Lang. A - High:
p= 0.7709
t-stat=-0.7492
df=40
sd=9.7135

Lang. B - Low:
p=0.0580
t-stat=-1.6069
df=40
sd=9.0378

S13. Unpaired *t*-test between Experiment 2 and 3, for ET (A) and IT (B).



S14. Grand-average ERPs at frontal (F1) electrode location comparing the 3 Blocks of the LP, for High (A) and Low (B) hierarchy conditions; these ERPs were time-locked to the beginning of the last long word of each sentence. The topography shows a slight global negativity in the scalp.

A

Source	Sum Sq.	d.f.	Mean Sq.	F	Prob>F
block	11.221	2	5.6103	2.84	0.0616
hier	0.971	1	0.97147	0.49	0.4844
actr	0.381	1	0.38104	0.19	0.6613
block*hier	7.509	2	3.75439	1.9	0.1532
block*actr	1.332	2	0.6658	0.34	0.7146
hier*actr	1.563	1	1.56308	0.79	0.3753
block*hier*actr	0.686	2	0.34308	0.17	0.8409
Error	308.49	156	1.9775		
Total	332.153	167			

B

Bloc 1 - Bloc 2:
p=0.0192
t-stat=-2.1774
df=27
sd=1.3960

Bloc 1 - Bloc 3:
p=0.1189
t-stat=-1.2071
df=27
sd=1.3014

Bloc 2 - Bloc 3:
p=0.8858
t-stat=1.2323
df=27
sd=1.1919

C

Bloc 1 - Bloc 2:
p=0.1972
t-stat=-0.8656
df=27
sd=1.2943

Bloc 1 - Bloc 3:
p=0.0015
t-stat=-3.2496
df=27
sd=1.5562

Bloc 2 - Bloc 3:
p=0.0048
t-stat=-2.7842
df=27
sd=1.4139

D

Bloc 1:
p=0.2573
t-stat=0.6604
df=27
sd=2.0094

Bloc 2:
p=0.0392
t-stat=1.8298
df=27
sd=1.7742

Bloc 3:
p=0.8640
t-stat=-1.1215
df=27
sd=1.9251

E

Bloc 1:
p=0.4585
t-stat=-0.1050
df=40
sd=1.3724

Bloc 2:
p=0.2534
t-stat=-0.6697
df=40
sd=1.0190

Bloc 3:
p=0.9575
t-stat=1.7662
df=40
sd=1.1638

F

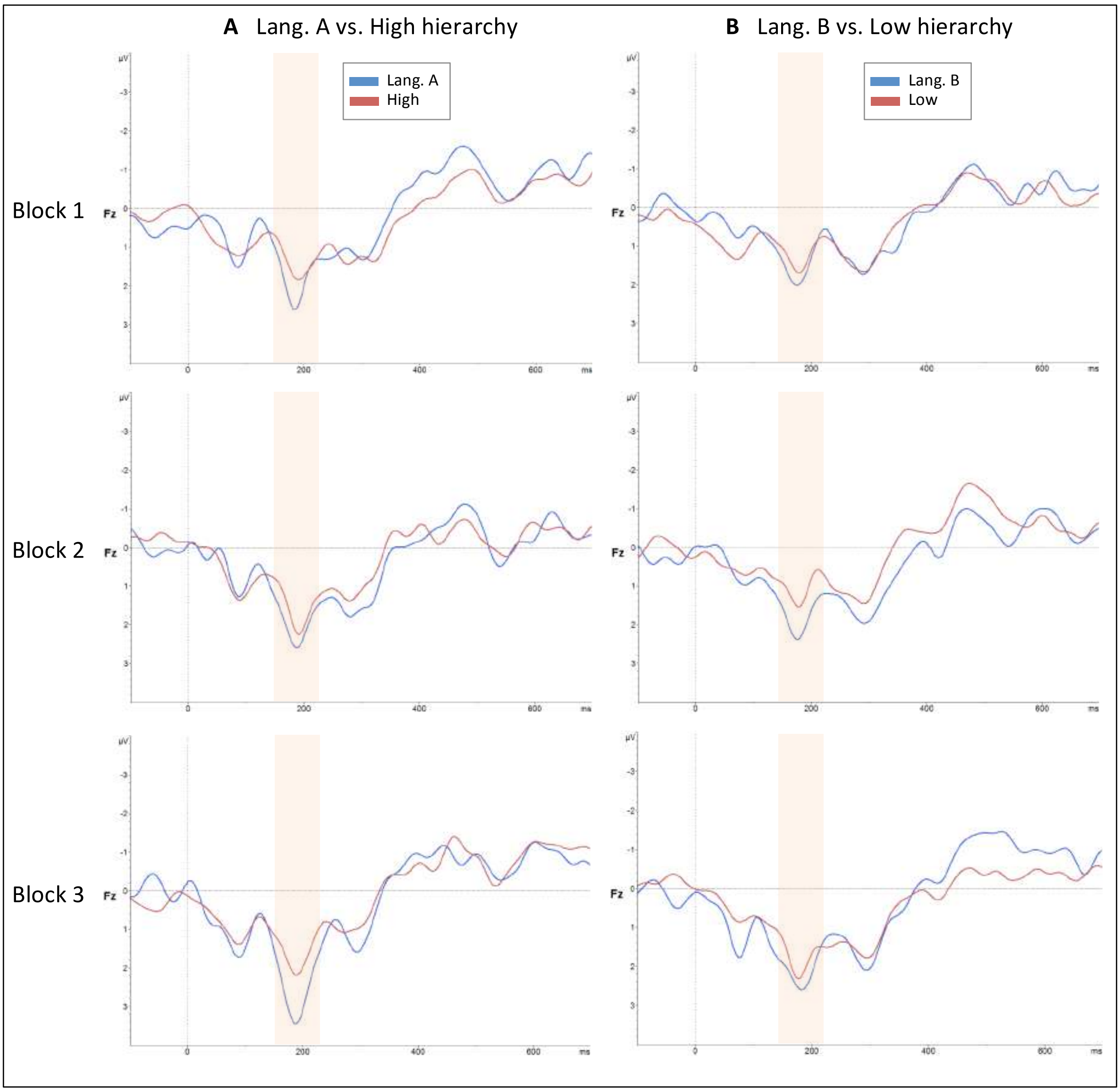
Bloc 1:
p=0.3535
t-stat=0.3785
df=40
sd=1.4298

Bloc 2:
p=0.4053
t-stat=0.2412
df=40
sd=1.4324

Bloc 3:
p=0.6471
t-stat=-0.3801
df=40
sd=1.5573

	Bloc 1 - Bloc 2:	Bloc 1 - Bloc 3:	Bloc 2 - Bloc 3:
G	p=0.1137 t-stat=-1.2670 df=13 sd=1.1760	p=0.0016 t-stat=-3.6125 df=13 sd=1.0532	p=0.0247 t-stat=-2.1659 df=13 sd=1.0687
H	Bloc 1 - Bloc 2: p=0.3115 t-stat=-0.5035 df=13 sd=1.0977	Bloc 1 - Bloc 3: p=0.0383 t-stat=-1.9239 df=13 sd=1.1373	Bloc 2 - Bloc 3: p=0.0818 t-stat=-1.4767 df=13 sd=1.1074

S15. A) ANOVA of the interaction Block - Hierarchy - Actress for P200. B) Paired *t*-tests between Blocks for the High hierarchy. C) Same for Low Hierarchy. D) Paired *t*-tests between High and Low hierarchy for each Block. E) Unpaired *t*-tests between Lang. A and High hierarchy. F) Same between Lang. B and Low hierarchy. G) Paired *t*-tests between Blocks for Lang. A. H) Same for Lang. B.



S16. Grand-average ERPs at frontal (Fz) electrode location comparing the P200 between Lang. A vs. High hierarchy (A) and Lang. B vs. Low hierarchy (B), for each Block.

A

Source	Sum Sq.	d.f.	Mean Sq.	F	Prob>F
word	36.917	1	36.9175	4.21	0.0428
hier	2.261	1	2.2606	0.26	0.6128
actr	0.915	1	0.9149	0.1	0.7474
word*hier	10.729	1	10.7291	1.22	0.2714
word*actr	1.494	1	1.4939	0.17	0.6807
hier*actr	5.488	1	5.4883	0.63	0.4308
word*hier*actr	0.27	1	0.2705	0.03	0.861
Error	912.566	104	8.7747		
Total	970.641	111			

B Word - Non-word:
p=0.1736
t-stat=0.9566
df=27
sd=2.9276

C Word - Non-word:
p=0.0007
t-stat=3.5678
df=27
sd=2.6210

D Word:
p=0.2939
t-stat=-1.0704
df=27
sd=4.4647

Non-word:
p=0.6931
t-stat=0.3989
df=27
sd=4.4419

E Word:
p=0.0013
t-stat=3.4612
df=40
sd=2.8593

Non-word:
p=0.0394
t-stat=2.1296
df=40
sd=2.5441

F Word:
p=0.7219
t-stat=0.3585
df=40
sd=3.0145

Non-word:
p=0.0281
t-stat=2.2791
df=40
sd=2.7496

G Word - Non-word:
p=0.0073
t-stat=2.8183
df=13
sd=2.6489

H Word - Non-word:
p=0.4602
t-stat=0.1019
df=13
sd=2.5631

S17. A) ANOVA of the interaction Word - Hierarchy - Actress for P300. B) Paired *t*-tests between Words for the High hierarchy. C) Same for Low Hierarchy. D) Paired *t*-tests between High and Low hierarchy for Words and Non-words. E) Unpaired *t*-tests between Lang. A and High hierarchy. F) Same between Lang. B and Low hierarchy. G) Paired *t*-tests between Words and Non-words for Lang. A. H) Same for Lang. B.

A

Source	Sum Sq.	d.f.	Mean Sq.	F	Prob>F
word	29.502	1	29.5017	4.99	0.0277
hier	1.475	1	1.4751	0.25	0.6186
actr	0.086	1	0.0855	0.01	0.9045
word*hier	3.294	1	3.2938	0.56	0.4572
word*actr	0.482	1	0.4817	0.08	0.7759
hier*actr	2.744	1	2.744	0.46	0.4973
word*hier*actr	0.006	1	0.0055	0	0.9757
Error	615.239	104	5.9158		
Total	652.826	111			

B Word - Non-word:
p=0.0190
t-stat=2.1828
df=27
sd=1.6569

C Word - Non-word:
p=0.0108
t-stat=2.4401
df=27
sd=2.9697

D Word:
p=0.3234
t-stat=-1.0059
df=27
sd=3.0115

Non-word:
p=0.8733
t-stat=0.1610
df=27
sd=3.7294

E Word:
p=0.9592
t-stat=-0.0515
df=40
sd=2.2001

Non-word:
p=0.7865
t-stat=-0.2727
df=40
sd=1.8767

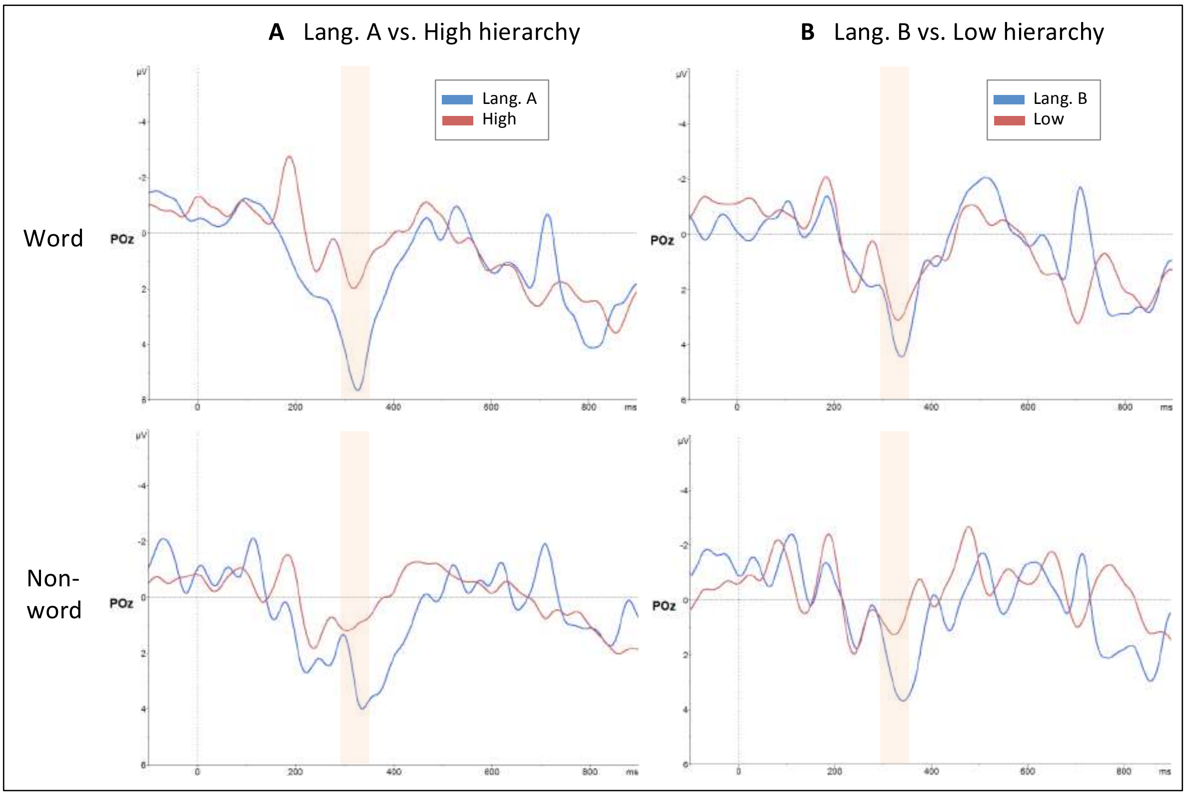
F Word:
p=0.2454
t-stat=-1.1789
df=40
sd=2.3805

Non-word:
p=0.5739
t-stat=0.5670
df=40
sd=2.6939

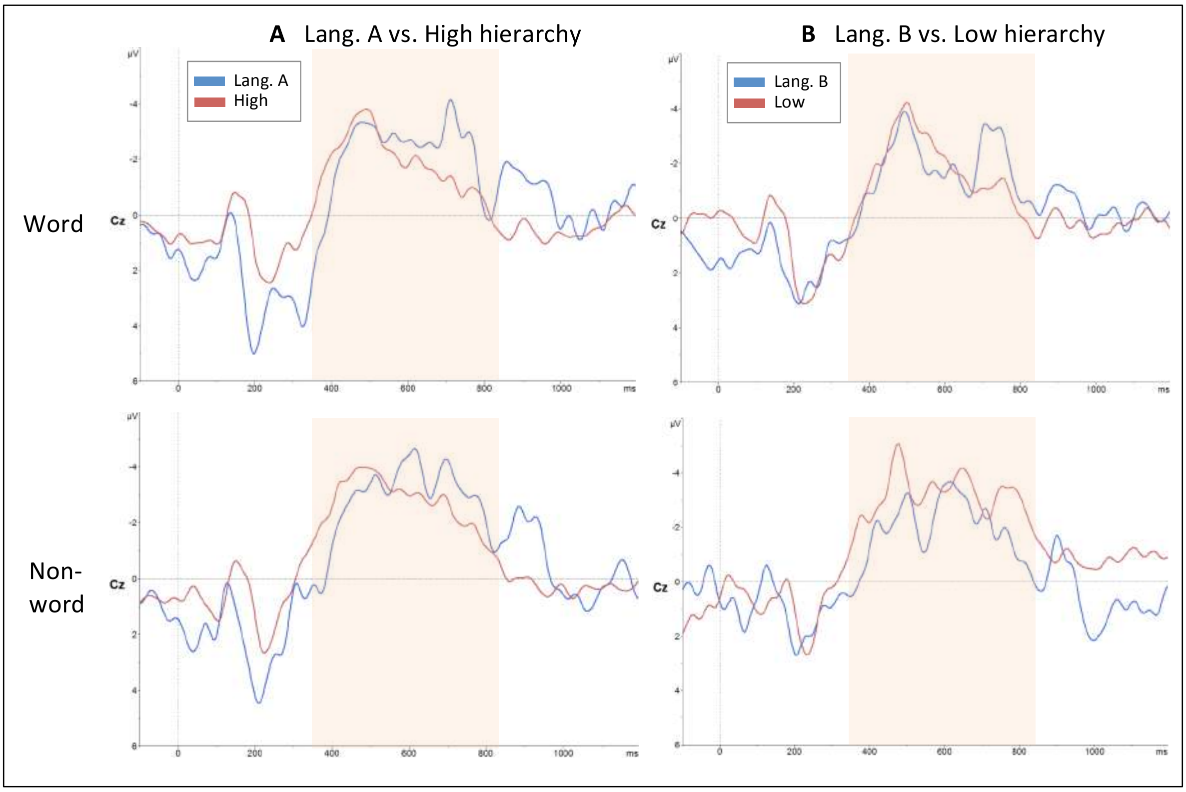
G Word - Non-word:
p=0.0389
t-stat=1.9140
df=13
sd=1.5911

H Word - Non-word:
p=0.5304
t-stat=-0.0778
df=13
sd=2.3612

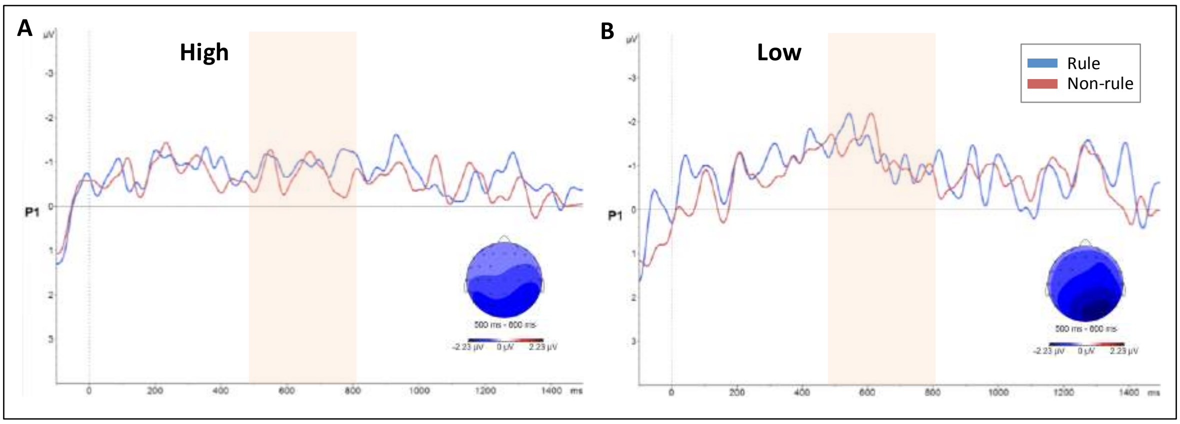
S18. A) ANOVA of the interaction Word - Hierarchy - Actress for N400. B) Paired *t*-tests between Words for the High hierarchy. C) Same for Low Hierarchy. D) Paired *t*-tests between High and Low hierarchy for Words and Non-words. E) Unpaired *t*-tests between Lang. A and High hierarchy. F) Same between Lang. B and Low hierarchy. G) Paired *t*-tests between Words and Non-words for Lang. A. H) Same for Lang. B.



S19. Grand-average ERPs at parieto-occipital (POz) electrode location comparing P300 between Lang. A vs. High hierarchy (A) and Lang. B vs. Low hierarchy (B), for Words and Non-words.



S20. Grand-average ERPs at central (Cz) electrode location comparing the N400 between Lang. A vs. High hierarchy (A) and Lang. B vs. Low hierarchy (B), for Words and Non-words.



S21. Grand-average ERPs at parietal (P1) electrode location comparing the Rule and Non-rule sentences, for High (A) and Low (B) hierarchy conditions. The topography shows a global negativity in the scalp.