The Influence of Language-specific Auditory Cues on the Learnability of Center-embedded Recursion

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Abstract

The learnability of center-embedded recursive structures has attracted much attention (Corballis, 2007; Friederici, 2004; Rey, Perruchet, & Fagot, 2012). However, most of the previous studies adopted the artificial grammar learning paradigm (Reber, 1967) and did not apply natural language stimuli. Rather, they applied synthetic meaningless training materials, which hardly represent the richness and complexity of natural language. Accordingly, in the current study, we attempt to tighten the link between artificial language learning and natural language acquisition in the auditory modality, by enriching our learning environment with phonological cues that occur in natural, spoken information; in particular, Chinese tones. In a grammaticality judgment task, we examined the syntactical processing by participants from different language backgrounds. Through the cross-language comparison between Chinese and Dutch native speakers, we aim to test the influence of language-specific phonological cues on processing complex linguistic structures. The results showed that tones had a more beneficial learning effect for Chinese than for Dutch participants. In other words, when participants learned a new language, they were likely to bring their own language routines implicitly from the familiar native language into processing the unfamiliar one.

Keywords: Phonological cues; Language-specific; Artificial language; Syntactical processing; Auditory modality

Introduction

The ability to use and understand hierarchical structures has been proposed to be a unique characteristic of human primates (Hauser, Chomsky, & Fitch, 2002; Fitch & Hauser, 2004). One of these complex structures is center-embedded recursion, which has attracted attention from various research domains (Corballis, 2007; Friederici, 2004; Rey, Perruchet, & Fagot, 2012). However, when center-embedded structures occur in natural language, such as the English sentence "*The dog that the cat chased ran away*", it appears to be difficult to understand and to process for human language users.

Although a large number of studies have investigated the processing of center-embedded recursion using artificial grammar learning paradigm, whether this type of structures can be learned still remains controversial (Conway & Christiansen, 2005; Conway, Ellefson & Christiansen, 2003; Li, Jiang; Guo; Yang & Dienes, 2013; Vicari & Adenzato, 2005). Moreover, most previous studies focused on the learning of center-embedded recursion in the visual modality (de Vries, Monaghan, Knecht, & Zwitserlood, 2008; Rey, et al., 2012), whereas learning the structures in the auditory modality, which deserves more research attention, was virtually neglected (Conway et al., 2003; Mueller, Bahlmann, & Friederici, 2010). This is quite surprising since the auditory modality is arguably more important than the visual modality for first language acquisition during infancy. Hence, experiments that aim at a proper understanding of how complex linguistic structures are acquired have to include it.

A recent study (Lai, Krahmer, & Sprenger, 2015) has demonstrated that learning such structures is indeed possible in the auditory modality within a 30-miniute exposure. Listeners were able to learn an artificial language, consisting of sequences with center-embedding (for example, non-word sequences following the structure of A_1B_1, $A_1A_2B_2B_1$, $A_1A_2A_3B_3B_2B_1$). Moreover, the results suggested that facilitative cues from previous experiments in the visual modality (Lai & Poletiek, 2011, 2013; Lai, Krahmer, & Sprenger, 2014), which were observed in the learning of visual center-embedded recursion, were also helpful in the auditory modality (Lai, et al., 2015). These cues pertained to 1) the order of the stimuli in the learning environment (incrementally increasing the complexity of the training input); 2) the total amount of stimuli presented (few specimen rather than many); 3) the frequencies with which the training stimuli were repeated (differential rather than uniform). All three factors turned out to improve the performance of the participants in judgments of grammaticality significantly, and performance was best when all three cues were combined.

More precisely, in Lai et al. (2014, 2015), there were three groups: a) a Starting-small (SS) group, which was trained with staged input. Participants saw 144 learning exemplars, ranging from the easiest to the most difficult; b) the Starting-less (SL) group, which saw less unique exemplars (36), but all exemplar were repeated for an equal number of time; c) the Starting-high (SH) group, which also received less unique exemplars (36), but exemplars were repeated for an unequal number of times. Results showed that all groups performed significantly above chance level. In addition, it was found that humans were able to extract center-embedded recursion in an auditory learning environment, when the training input was arranged incrementally with increasing complexity. The starting small facilitation effect thus also holds true for the auditory modality. Moreover, the SH group performed significantly better than both the SS and SL group. The small diversity in exemplars of the SH group did not hinder learning CE recursion, but helped participants to focus on regularities. Additionally, the repetition of that limited amount of exemplars enables learners to become acquainted with the grammatical structures and to solidify their memory of the recursive structures.

The adoption of artificial grammar learning paradigm has been criticized for having low ecological validity and can hardly mimic the complete natural language acquisition procedure (Forkstam, Jansson, Ingvar, & Petersson, 2009). The simplified artificial language does not have the richness and complexity of the real natural language in various dimensions, such as the large amount of vocabulary, semantics, and phonology, etc. (Arciuli & Torkildsen, 2012). Therefore, it remains under speculation to which degree results from artificial language learning can be generalized to the actual language acquisition process. Accordingly, the purpose of the current study is to create a stronger link between artificial language learning and natural language learning. It is crucial that the statistical learning study that we conduct can not only simulate the richness of natural language environment, but also maintain its particular advantage, namely, the strict control over prior language knowledge and the learning material (Arciuli & Torkildsen, 2012). Therefore, we retain the artificial grammar paradigm, but we supplement it by adding a property of natural languages, namely, phonological cues. More precisely, using the auditory modality, Chinese tones were added to the artificial learning input. Firstly, we examine whether the phonological property from natural language would influence the processing of auditory center-embedded recursion. Secondly, we investigate whether listeners from different language background would process the complex structures differently. Thirdly, we studied whether the facilitative cues from our previous study (Lai et al., 2015) also worked in the presence of phonological cues. Previous studies showed that learners relied on native speech routines in their own language while learning to segment a new language (Vroomen, Tuomainen, & de Gelder, 1998, Saffran, Werker, & Werner, 2006). For example, Vroomen et al. (1998) found that word stress and vowel harmony had a differential impact on Finnish, Dutch, and French listeners. Similarly, in word segmentation studies, it has been shown that adult learners profited from a “metrical segmentation strategy”, which treated language-specific factors as signals in recognizing word boundaries (Saffran, et al., 2006; Tyler, 2006). For example, English listeners tended to consider strong syllables as the onsets of upcoming words, since English is a stress-timed language and routinely most of English words start with strong syllables (Cutler, & Norris, 1988).

These previous studies indicated that phonological cues from natural language indeed affected participants differently according to their natural language. The above phenomena were observed in word segmentation tasks. We examine whether they also exist in syntactical processing tasks. We focus on tones in Chinese. We hypothesize that tones, which are present in Chinese but absent in most European languages, such as Dutch, would have a different influence on Chinese and Dutch listeners, when they are processing center-embedded structures in the auditory modality. In a grammaticality judgement task, we exposed Dutch and Chinese participants to two sets of artificial input, one with and the other without Chinese tones. Chinese are expected to make use the existence of tones, while Dutch are not. We also test whether the optimal learning strategies in our previous experiment (Lai et al., 2015) succeed when the input resembles natural language more closely.

Methods

Participants

Fifty Dutch speakers (25 female, mean age 21.68 year, SD 2.12) from Tilburg University and fifty Chinese speakers (38 female, mean age 20.38 year, SD 3.17) from Sun Yat-sen University participated in this study for course credit. None of the Dutch participants learned Chinese before the experiment, and vice versa. No participants had prior knowledge about the experiment. All the participants had normal hearing abilities.

Materials and design

Non-word sequences were generated by a center-embedded recursive rule, possessing the pattern A_1B_1, $A_1A_2B_2B_1$ or $A_1A_2A_3B_3B_2B_1$ (c.f. Lai, et al., 2015). There were two sets of stimuli: one was the non-tonal set, which was recorded by a native Dutch speaker; whereas the other one is the tonal set, which was recorded by a native Chinese speaker. Both speakers were instructed to read sequences in a natural way as if pronouncing natural speech in their own language. The speed of reading and intonation were held constant. For example, each sequence was pronounced syllable by syllable (approximately 400 ms per syllable). We also checked the validation of our experimental material by conducting an intelligibility test prior the main experiment. The test showed that all Dutch utterances were intelligible for Dutch native speakers, and Chinese utterances were also clear to Chinese native speakers. Listeners in the intelligibility test would not participate in the main experiment.

For the stimuli set, the sequences consisted of two, four, or six consonant-vowel syllables. The syllables were constructed using six consonants (/b/, /p/, /d/, /t/, /n/, and /m/) and two vowels (/i/, /e/, /o/, and /a/). We created a set of A-syllables (i.e. bi, be, di, de, ni, ne), and a set of B-syllables (i.e. po, pa, to, ta, mo, ma). The A-B mapping was not random. Not every A can go with every B-syllable. Instead, the pairs of consonants (b-d, d-t, n-m) determined the relatedness of AB pairs. None of the sequences existed in Dutch or Chinese lexicons.

For the Chinese stimuli set, the same set of (lexical) syllables was used, while adding Chinese tones to the syllables. A tonal syllable is characterized by two factors, namely pitch height (fundamental frequency) and contour (with a level, low-rising, high-falling, or dipping shapes) (Wang & Saffran, 2014). Mandarin Chinese employs tones to differentiate lexical meanings. These special variations in Chinese tones appear as “truly foreign acoustic cues to the ears of non-tonal speakers” (Wang & Saffran, 2014). In the current design, two distinctive tones, i.e. Tone 2 (low-rising) and Tone 4 (high-falling), were selected to differentiate Category A syllables from Category B syllables. Syllables with tones were strictly selected to avoid producing words with semantic meanings.

Sequences were read out with a natural intonation. The pattern was held consistent across all stimuli. Both Dutch and Chinese utterances were presented at the same volume and in the same manner to participants in all conditions. We measured the pitch contour of the recorded sequences by examining their acoustical parameter, namely, the fundamental frequency (F0), as depicted in Figure 1.

As displayed in Figure 1, for four-syllable sequences, Dutch- and Chinese utterances possessed distinctive features. On the one hand, the pitch of Dutch utterances was comparatively flat. The pitch of the third syllable was slightly lower than the others, marking the start of the second half of the sequences. (For the 6-syllable ones, the lower pitch started at the fourth syllable). The pattern was held consistent. On the other hand, for each Chinese utterance, the first half had a low-rising trend, and the second half had a high-falling pattern.

Procedure

Participants were randomly assigned into one of the four groups: Dutch listener --Tonal stimuli, Dutch listener --Non-tonal stimuli, Chinese listener --Tonal stimuli, and Chinese listener --Non-tonal stimuli. The experiment consisted of two phases, learning and testing. Participants were informed that they were participating in a simple language learning task. They were not provided with any information about the underlying center-embedded recursive grammar. In the learning phase, participants were instructed to listen to the artificial sequences attentively. Each trial starts with a beep (400 ms), followed by a learning sequence in a syllable-by-syllable method and then the inter-stimulus interval (1000 ms).

Regarding to the complexity of the exemplars, there was an equal number of all three levels, i.e. zero-, one-, and two-level of embedding (LoE) (for example, *bepa*, *beditopa*, *bedinimatopa*). In the learning phase, in total there were 144 sequences, consisting of 36 unique exemplars with a

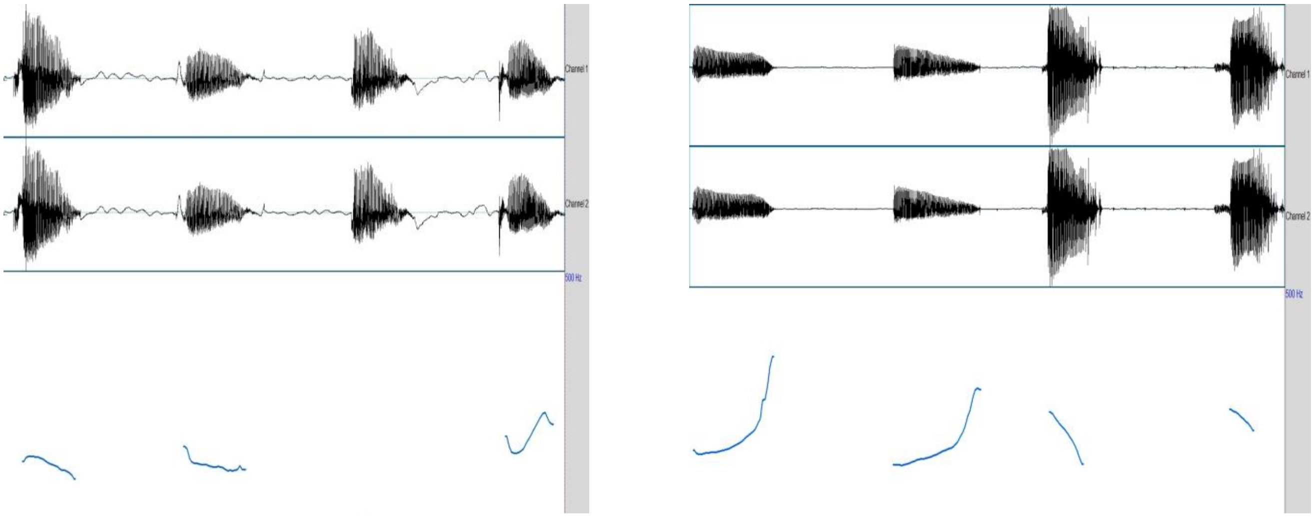

Figure 1. Comparison of fundamental frequency (F0) contours between Dutch and Chinese sequences. For example, the F0 of a 4-syllable sequence (dibipata), on the left is the Dutch utterance and on the right is the Chinese one with tones.

repetition. Therefore, there were 12 unique sequences for each LoE. Exemplars were repeated according to their occurrence probability, which was determined by the center-embedded recursive grammar. High probable exemplars were repeated more frequently than low probable ones. Specifically, 0-LoE sequences were repeated more times than 1-LoE ones, which in turn occurred more times than 2-LoE ones. In the testing phase, there were 72 unique sequences, half grammatical and half not. Ungrammatical items were produced by mismatching the related syllables with unrelated ones. The test sequences, which also had three levels of complexity, occurred in a random manner, instead of being arranged from the simplest to the most difficult. Participants were required to make judgments whether the test sequences were governed by the same rule as the one in the learning phase. If they agreed that the test sequences were generated by the same rule that generated the learning sequences, then they pressed "YES"; if not, then "NO".

Prior to the formal start of test phase, a practice session with four trials familiarized the participants with the forthcoming procedure. Practical trials would not occur again in formal tests. After the experiment, participants were debriefed.

Results

A one-sample t-test showed that all groups performed significantly above chance level accuracy: Dutch participants listening to Non-tonal set, M= .60, SD= .08, t (24) = 6.25, $p < .001$; Dutch participants listening to Tonal set, M= .58, SD= .10, t (24) = 4.00, $p < .001$; Chinese participants listening to Non-tonal set, M = .61, SD= .10, t (24) = 5.50, $p < .001$; Chinese participants listening to Tonal set, M= .69, SD= .14, t (24) = 6.79, $p < .001$.

An ANOVA showed that there was a main effect of native language, F (1, 96) = 8.22, p = .005, η_p^2 = .08. Generally, Chinese speakers (M = .65, SE = .02) scored significantly higher than Dutch speakers (M = .59, SE= .02). There was no main effect of tonality of input, F (1, 96) = 1.20, p = .276, η_p^2 = .12, but crucially the interaction between native language and tonality was significant, F (1, 96) = 5.35, p = .023, η_p^2 = .053 (as shown in Figure 2).

When Chinese speakers listened to stimuli with tones, they scored higher than they did when listening to stimuli without tones, t (48) = 2.14, p = .037, r^2 = .09. By contrast, Dutch speakers performed similarly, irrespective of whether they were exposed to stimuli with or without tones, t (48) = 1.01, p = .320, r^2 = .02. Therefore, the presence of tones advanced the learning performance of Chinese participants, but not of Dutch participants.

Furthermore, as depicted in Figure 3, we observed a main effect of grammaticality, F (1, 192) = 26.60, p = .000, η_p^2 = .122, and a main effect of group, F (3, 192) = 3.44, p = .018, η_p^2 = .051 (Table 1), but no significant interaction, F (3, 192) = .250, p = .861, η_p^2 = .04. Generally, scores on grammatical items (M = .67, SE= .01) were significantly higher than on ungrammatical items (M = .57, SE= .01), $p < .001$.

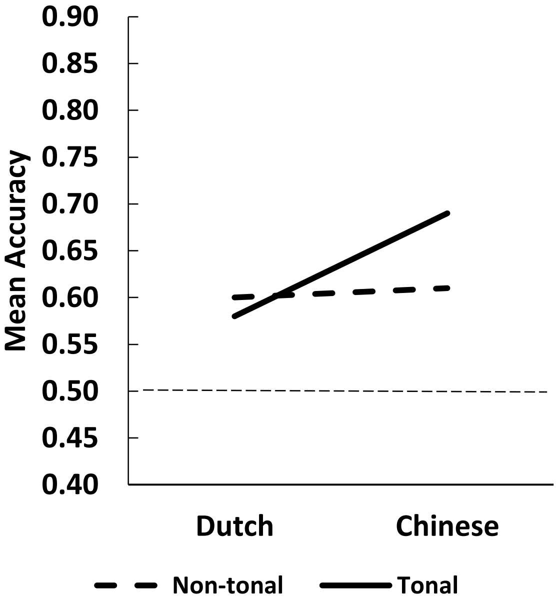

Figure 2. Mean accuracy of Dutch and Chinese participants on tonal and non-tonal test sequences. The dotted line represents chance level (M= .50).

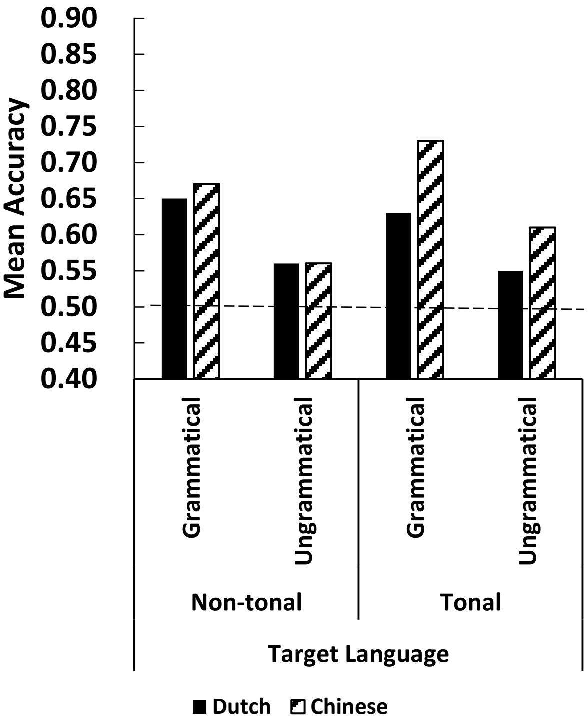

Figure 3. Mean accuracy of Dutch and Chinese participants on the grammaticality of both tonal and non-tonal test sequences. The dotted line represents chance level (M= .50).

Discussion

In a complex linguistic structure learning experiment, we added Chinese tones onto the non-word artificial input and investigated whether listeners' learning performance would be influenced by their native language background. Firstly, we replicated the significant learning effect obtained by the starting-high strategy in previous research (Lai et al., 2014; 2015). All groups achieved better than chance accuracy in discriminating grammatical sequences from non-grammatical ones. The successful learning overall is potentially explained by the efficient interaction of three factors: a) the incremental ordering (the most fundamental associations being presented first, then dependencies with one embedding, and in the end the most complex ones with two embedding) helped learners deconstruct the complexity, by arranging the learning input in a more efficient and easier way; b) the small set of exemplars helped participants focus on the underlying regularities. As a result, participants avoided being easily confused by the diversity and variations of the large amount of unique exemplars; c) the repetition of exemplars helped them consolidate memories. Therefore, the current results contribute to the debate about the conditions under which complex statistical patterns can be learned best (Conway et al., 2003; Perruchet & Rey, 2005). For instance, unlike the current study with a relatively small set of stimuli, Gomez (2002) and Gomez and Maye (2005) suggested that higher variability in exemplars can actually help participants learn regularities. They found that a token "*X*" can facilitate learning of *"aXb"* structures. Being sensitive to the degrees of stimulus complexity, statistical learning deserves further research on the composition of learning input.

Crucially, our results revealed that the nature of participants' native language, instead of the target language, had an important influence on syntactical processing of center-embedded recursive structures. Chinese participants performed better, when listening to stimuli with tones than without. Chinese participants might possess comparatively higher sensitivity towards the tonal variations. This indicates that when the target artificial language contained language-specific cues, participants made use of these phonological cues that they were familiar with from their native language. In contrast, these lexical tones had no noticeable impact on Dutch participants when listening and processing recursive structures, presumably because tones are not present in Dutch. Regarding this aspect of second language acquisition, our results confirm that learners might benefit in learning the new language, when the target language shares properties from their native language.

Recent cross-linguistic research has also probed into the interplay between prior linguistic experience and subsequent (second) language learning (Onnis & Thiessen, 2013). For instance, in a tonal word vs. non-word discrimination task, Mandarin bilinguals and monolinguals largely outperformed English monolinguals (Wang & Saffran, 2014). On the one hand, this might be due to the prior knowledge matching with the target language or not; on the other hand, it might be that the underlying cognitive mechanism for tonal language users leads to better performances in more domain-general cognitive tasks, compared to non-tonal language users, as Bidelman, Hutka, and Moreno (2013) suggested. Our results, which showed that Chinese scored general higher than Dutch participants in this task, were consistent with this potential account. Since our stimuli were recorded by different speakers (Chinese for the tonal set and Dutch for the non-tonal set), it is also conceivable that other factors, besides the presence of tones, might influence learning performance. Further research on language-specific statistical biases is needed.

Furthermore, the previous literature mainly focused on the contribution of phonological cues in speech processing, e.g. phrase discrimination from sound stream (Bion, Höhle, & Schmitz, 2007). Our results manifested that phonological cues can facilitate syntactical processing in a higher level, namely, phrase structure grammar (Chomsky, 1957), which produces hierarchical center-embedding.

In addition, being consistent with previous research (Lai, et al., 2014; 2015), we found that generally participants were more accurate in recognizing grammatical sequences than ungrammatical ones. However, our current data showed that with the help of tones, Chinese participants improved in detecting ungrammatical sequences.

Conclusion

The present study displayed the crucial influence of language-specific cues on learning center-embedded structures via the auditory modality. The phonological tone cue had a different impact on speakers with a tonal and non-tonal background. As predicted, when the target language shares the phonological characteristics of participants' native language, learning was enhanced. This finding sheds further light on second language acquisition. Further more studies are needed to incorporate more language-specific cues in order to conduct the comparison between artificial language learning and second language acquisition.

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