ACOUSTIC AND PHONOLOGICAL MEMORY IN L2 VOWEL PERCEPTION

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This study examined the role of acoustic memory (AM) and phonological short-term memory (PSTM) in the perception of English /iː/ and /ɪ/ by Spanish/Catalan L2 learners. A sub-goal was to explore whether PSTM is related to AM. To assess participants' AM capacity a novel serial nonword recognition task using rotated speech was designed. The findings of the study were consistent with previous research regarding Spanish/Catalan learners of English over-reliance on temporal cues when perceiving the target contrast. The main hypotheses were not supported, as participants' L2 vowel perception was not significantly affected by individual differences in AM and PSTM. Nonetheless, AM and PSTM scores were found to be unrelated to one another, suggesting that measures of memory storage for speech-like nonwords and rotated-speech nonwords tapped on two different cognitive skills.
Keywords: L2 vowel perception; acoustic memory; phonological memory

1. Introduction

Although age of onset of L2 learning is still believed to be the best predictor of target-like pronunciation (Long 1990), research on L2 speech learning has identified several other sources of inter-subject variation, such as quality and quantity of input (Moyer 2009), amount of L1 and L2 use (Flege and Liu 2001), phonetic talent (Rota and Reiterer 2009), musical ability (Gottfried 2007), and phonological short-term memory (Cerviño-Povedano and Mora 2011; MacKay *et al.* 2001). The present study explores the effect of individual differences in cognitive ability on L2 vowel perception focusing on Spanish/Catalan learners' difficulty in perceiving the English /iː/-/ɪ/ contrast (Escudero and Boersma 2004). The aim is to investigate the role of acoustic memory (AM) and phonological short-term memory (PSTM) in learners' ability to rely on quality rather than duration cues in vowel perception.

PSTM refers to an individual's capacity to retain verbal–acoustic information temporarily in a short-term memory store (Baddeley and Hitch 1974). PSTM has been found to be a predictor of L2 language learning in adults in various domains of L2 competence, including oral fluency (O'Brien *et al.* 2007) and L2 speech perception (MacKay *et al.* 2001). Previous findings suggest that Catalan/Spanish EFL learners with higher PSTM capacity use L2 cue-weighting in the perception of L2 vowel contrasts in a more native-like manner, attending to both the durational and spectral information of a sound to a greater extent than lower PSTM learners (Cerviño-Povedano and Mora 2011). AM, which plays an important role in the speech perception process, is an auditory sensory memory store retaining speech stimuli at a pre-categorical level, i.e. prior to phonological encoding, for further processing (Crowder and Morton 1969). In

this study AM is operationalized as an individual's memory capacity for the temporary storing of non-verbal speech-like acoustic information. This information cannot be phonologically encoded and therefore cannot be assimilated to listeners' phonetic categories for L1 or L2 sounds. Previous research has shown that whereas AM plays a significant role in within-category vowel discrimination, PSTM is involved in between-category discrimination (Darwin and Baddeley 1974; Cowan and Morse 1986). Thus, AM may contribute to L2 learners' discrimination ability for L2 vowels, as it may be involved in learners' ability to perceive differences between L2 sound categories as well as cross-language differences between L2 and L1 sounds, especially within categories.
The present study aimed at exploring the contribution of AM and PSTM to non-native speakers' perception of the English tense-lax vowel contrast /iː/-/ɪ/. We hypothesized that individuals with greater AM capacity might be more sensitive to differences in acoustic information between perceptually similar L2 vowels and perceptually close L2-L1 vowel pairs. This perceptual advantage may facilitate the acquisition of native-like cue-weighting and the development of more accurate, target-like phonetic representations for L2 vowels. Because AM and PSTM are essentially different in that PSTM operates at the phonological level whereas AM operates at the acoustic/phonetic level, we hypothesized that both types of memory would not necessarily be related to one another despite their potential contribution to L2 speech perception.

The study was driven by the following research questions:

1. Are L2 learners with higher AM and PSTM better able to rely on spectral information than lower ability learners in the categorization of English /iː/ and /ɪ/?
2. Is AM independent from PSTM?

2. Methodology

The participants in the study (*N*=94, mean age: 22.73) were L1 Catalan/Spanish undergraduate students in the English Studies Degree at the University of Barcelona. The participants' self-estimated proficiency level ranged from intermediate to advanced (mean: 7.01; range: 5-9 on a 10-point scale). After completing a language background questionnaire, participants performed 4 computer-based tasks: two memory tasks (AM and PM), a vowel categorization task, and a vocabulary size task that was deemed to control for inter-subject differences in proficiency level.

Because previous research has found AM to be related to the perception of either speech (Diaz *et al.* 2008) or non-speech (Morton *et al.* 1981), in this study AM was assessed using rotated speech stimuli. Scott *et al.* (2000) provide evidence that speech-specific information is processed mainly in the left temporal lobe and that rotated speech can also activate the region which responds to the presence of phonetic information while not activating the region that responds to intelligible speech stimuli. Rotated speech is acoustically as complex as speech but it cannot be phonologically encoded, and therefore cannot be sub-vocally rehearsed (see Figure 1).

AM was measured through a serial nonword recognition (SNWR) task using a rotated speech version of the Catalan 144 nonword stimuli used in the PSTM task. In order to perceive a shift in the position of an item within one of the two sequences in a test trial participants had to rely on the acoustic information stored in AM, as rotated speech nonwords prevented listeners from using phonological coding and storage. The AM task (4 practice trials + 32 experimental trials) consisted of 3-, 4-, 5- and 6-item length sequence pairs (nonword ISI=200ms; sequence ISI=750 ms). Each trial consisted

of two sequences of rotated speech nonwords which were either the *same* or *different* (one item changed position). Participants heard the sequences of rotated nonwords distributed in blocks of increasing length, and pressed a key to respond whether the sequences were the *same* or *different*. Eight trials (4 same and 4 different) at each sequence length were randomly presented. The measure of AM capacity was a weighted score (out of 144) obtained by assigning 3, 4, 5 or 6 points to every correctly identified sequence pair according to sequence length (O'Brien *et al.* 2007). A similar SNWR task was used to measure PSTM. It consisted of 144 one-syllable CVC Catalan nonwords organized into sequences of 5-, 6- and 7-item length (nonword ISI= 300ms; sequence ISI= 1000ms), with eight pairs of sequences (4 same and 4 different) at each item length. The task and scoring procedure was the same as that used in the SNWR for AM.

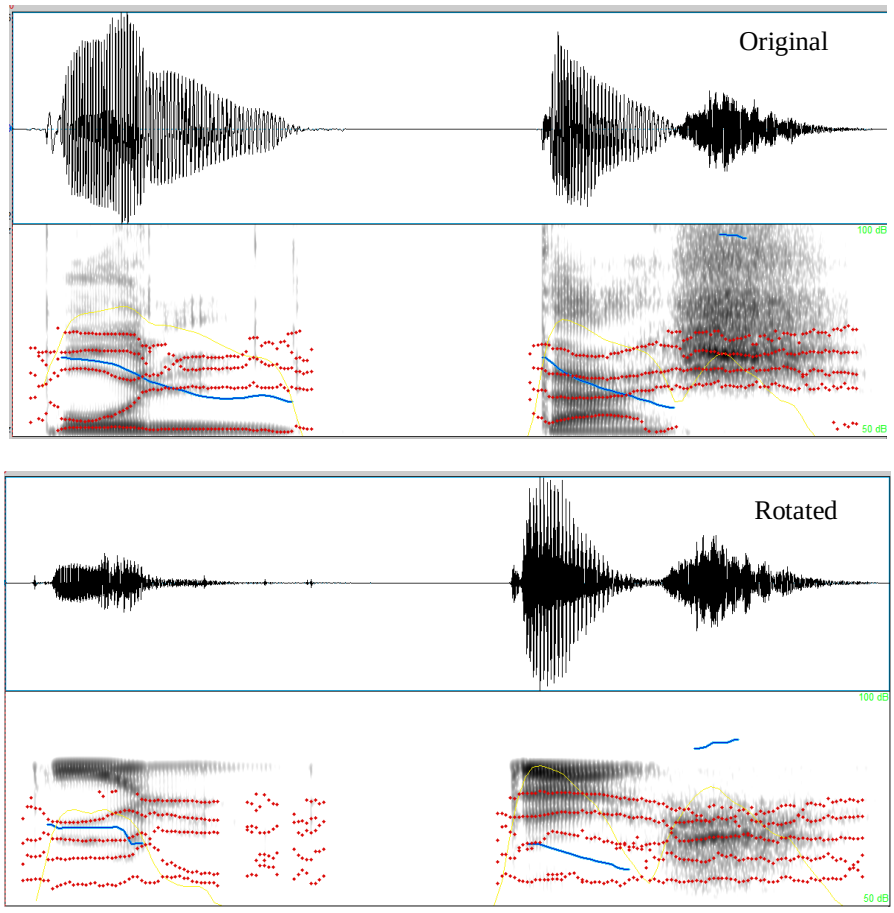

Figure 1: Example of rotated speech stimuli: Catalan nonwords: [puʎ], [taʃ]

Participants next performed a word identification task used to assess their perceptual phonological competence and cue-weighting in vowel perception (Ylinen *et al.* 2010). This task was a two-alternative forced choice identification of six CVC minimal pairs contrasting English /i ː/ and /ɪ / produced by six different talkers. The task included 72 natural and 72 manipulated stimuli. Manipulated stimuli were created by shortening the tense vowel /i ː/, so that its duration matched that of the lax vowel /ɪ /, and by lengthening the lax vowel to match the duration of its tense counterpart. The measure of phonological competence was the percentage of correct identifications of natural and manipulated tense and lax vowels.

3. Results

Because our participants were Spanish/Catalan bilinguals and the PSTM task was based on Catalan nonwords, we first assessed language dominance effects on the PSTM scores. A repeated measures ANOVA with *language dominance* (Catalan or Spanish) as the between-subjects factor and *item length* (5, 6, 7) as the within-subjects factor revealed that PSTM did not significantly vary as a function of language dominance ($F(1, 82)=.469$; $p=.495$), so participants were all included in a single group in further analyses (see Figure 2). The main effects for item length were significant ($F(2, 81)=44.15$; $p<.001$): further pairwise comparisons showed that differences were significant between 5-, and 6-item lengths ($p<.001$), but non-significant between 6- and 7-item lengths ($p=.177$). The *language dominance* x *item length* interaction was not significant ($F(2, 81)=.95$; $p=.391$). No language-dominance effects could have affected the AM scores, as the task did not involve phonological encoding.

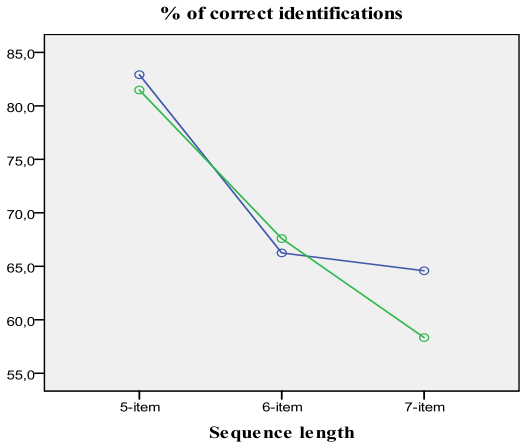

Figure 2: SNWR. Effects for L1/sequence item length

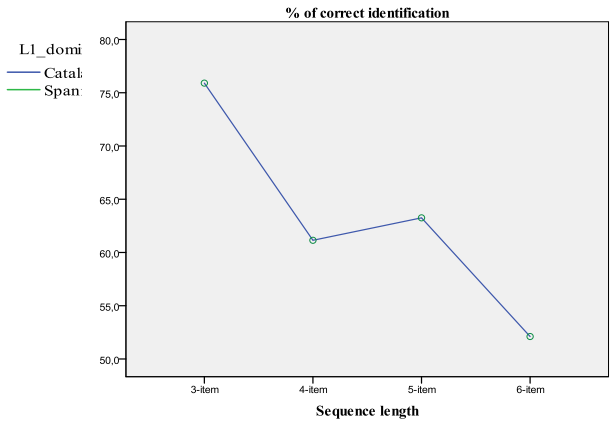

Figure 3: AM. Effect for sequence item length

As regards the AM task ($N=83$), a repeated measures ANOVA yielded a significant main effect for item length ($F(3, 80)=22.49$; $p<.001$) (see Figure 3). Further Bonferroni-adjusted pairwise comparisons revealed that differences were significant between 3-, and 4-item lengths ($p<.001$), 5- and 6-item lengths ($p<.001$), but non-significant between 4- and 5-item lengths ($p=1.0$). These results suggest that the adapted SNWR task with the rotated speech stimuli worked reliably as a measure of acoustic storage. PSTM and AM scores were found to be unrelated to one another (*Pearson* $r=.004$, $p=.973$), suggesting that these two auditory memory measures were tapping on two different memory capacities for auditory storage.

In the WI task, learners were found to over-rely on duration when categorizing English /iː/ and /ɪ/. Differences in the percentage of correct vowel identification between natural and manipulated vowels were statistically significant, with overall correct scores being much higher for natural ($M=70.17$, $SD=13.02$) than manipulated ($M=46.56$, $SD=20.57$) stimuli (Wilcoxon $Z=7.7$, $p<.001$). Percent correct identification scores were found to be unrelated to individual variables (e.g. age of onset of L2 learning, % daily use of English, self-reported proficiency level or pronunciation) as well as the vocabulary size measure and the two cognitive measures of auditory storage,

AM and PSTM. Participants (*N*= 84) were assigned to two PSTM groups (Low vs. High ability) on the basis of the SNWR scores through median split (range= 39-131, median= 100) and inter-group differences in mean correct identification of natural and manipulated stimuli were assessed through Mann-Whitney U Tests, which revealed non-significant differences between Low- and High-PSTM groups (*U*=.775, *p*=.984; *U*=.773, *p*=.973). The same procedure was used to assign participants to Low and High AM ability groups (range= 45-125, median= 88). The same comparisons yielded no statistically significant differences between Low- and High-AM groups (*U*=.722, *p*=.846; *U*=.683, *p*=.554).

Vowel	/i:/				/ɪ /			
Stimuli	NAT		MAN		NAT		MAN	
Group	LOW	HIGH	LOW	HIGH	LOW	HIGH	LOW	HIGH
PSTM *N*=37(low) *N*=42(high)	73.72 (14.61)	76.78 (15.24)	49.47 (22.43)	52.05 (25.22)	76.80 (14.59)	74.47 (16.38)	50.90 (16.68)	51.05 (21.18)
AM *N*=38(low) *N*=39(high)	73.61 (16.11)	76.85 (13.27)	51.46 (23.46)	49.35 (23.60)	76.46 (17.67)	73.57 (12.82)	53.28 (20.18)	47.43 (16.62)

Table 1: PSTM and AM scores on WI task for Low and High ability groups (*SD* in parentheses)

These findings suggested that, contrary to our hypothesis and expectations, there was no relationship between the two cognitive variables and the measure of participants' phonological competence operationalized as level of target-like cue-weighting.

4. Discussion and conclusions

The aim of this study was to explore the effect of inter-subject differences in AM and PSTM on the target-like weighting of duration and spectral cues in L2 vowel perception. To accomplish this goal we designed a novel test to measure participants' AM capacity. In accordance with previous research (Escudero and Boersma 2004), the WI task showed that Spanish/Catalan learners of English over-rely on temporal cues in the categorization of English /iː/ and /ɪ /. However, the main hypotheses of the present study were not supported. After assigning participants to Low and High ability groups as a function of PSTM and AM no significant between-group differences emerged. High ability groups were not found to have an advantage over Low ability groups on L2 vowel perception. Thus, L2 learners with higher cognitive ability in auditory storage (PSTM and AM) were not better able to rely on spectral information than lower ability learners in the perception of the English tense-lax /iː/-/ɪ / contrast. These results do not support previous findings showing an advantage of individuals with higher PSTM capacity in the target-like perception of L2 sounds, despite the fact that L2 learners with higher PSTM tended to obtain slightly higher scores in the WI task. One possible explanation of these unexpected results is that the group of participants in this study was too homogeneous as regards proficiency, L2 experience and phonological training. The absence of a correlation between the AM and PSTM measures suggest that they assessed two different cognitive skills. The significant effect of sequence item length on participants' AM scores indicates that the task worked reliably as a means of obtaining

a measure of "acoustic" auditory memory different from the measure of "phonological" auditory memory obtained through the PSTM task.

Thus, it is still unclear how cognitive variables such as AM and PSTM affect L2 perceptual ability providing L2 learners with an advantage in L2 phonological learning. Other individual differences such as musical ability, phonetic talent or ability for oral mimicry still remain largely under-researched and deserve further investigation.

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