The presentation order effect and the role of linguistic experience: a cross-linguistic perceptual study on an [i]-[e] continuum.

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1. ABSTRACT

It has been proposed that a vowel change is harder to perceive when the first element in a pair occupies an extreme position in the acoustic space, based on the assumption that peripheral vowels tend to perceptually 'absorb' neighbouring vowels. Using an articulatory model, we have prepared a 10-vowel continuum extending from an /i/ (stimulus no. 1, the most extreme) to a mid-close /e/ (stimulus no. 10) and have conducted two experiments with French, Southern Italian (Salentinian), Brazilian Portuguese and Spanish listeners. In Experiment 1, 106 listeners were requested to identify the ten 350-ms stimuli either as /i/ or /e/. Results revealed a non-linear transition from /i/ to /e/, with the boundary being located in different positions for three of the four languages. Ninety-six listeners from the general pool participated in Experiment 2 (a slightly modified AX roving discrimination task) and pairs of stimuli - differing in one or two steps along the continuum - were presented in both orders. An order effect being attested only for French and Salentinian Italian and only for extreme, /i/-like stimuli, we postulate that the asymmetry phenomenon is triggered by peripherality on the F2' dimension given the focal nature of the latter tokens. In addition, given that the effect is found only for these two languages, we suggest that it is mostly a linguistic - and not a psychoacoustic - phenomenon based on the cognitive status of F2' in a system.

2. INTRODUCTION

The 'presentation order effect' (POE) - also known as 'phenomenon of asymmetry' - can be resumed in Polka & Bohn's (2003) definition: "Asymmetries in vowel perception occur such that discrimination of a vowel change presented in one direction is easier compared to the same change presented in the reverse direction".

In a very intriguing paper, Medin & Barsalou (1987) discuss the notion of 'reference points' (Rosch, 1975), which can be "either salient values on dimensions that structure categories or they can be prototypes that contain characteristic and ideal attributes of the category" [pp. 474-475]. In vowel perception, various possible reference points have been proposed: the centre of the vowel space (Repp & Crowder, 1990), category prototypes (Kuhl, 1991), the edges (periphery) of the vowel space (Polka & Bohn, 2003).

According to Kuhl (1991), the reference points responsible for order effects are none other than phonetic prototypes, which she calls 'perceptual magnets'. This suggests that, if a continuum spanning two distinct phonemic categories were to be used, order effects would occur around both ends of the continuum (as long as the endpoints are considered as functional exemplars of their respective categories). Nonetheless, Sawusch *et alii* (1980) found a sensitivity change only for the /i/ anchor and not for /I/. In an adaptation experiment, Morse *et alii* (1976) obtained, using an /i/-/ɪ/-/ɛ/ continuum, an adaptation effect only for /i/ and /ɛ/ and not /ɪ/. Thyer *et alii* (2000) have also been unable to find a magnet effect for Australian vowels.

Since Kuhl's (1991) original paper, a number of papers have treated the order effect and for various languages [see Polka & Bohn (2003) for a summary for English and German from infant data] and most of them have focused on the role of peripherality in the vowel space. That is, whereas Kuhl considers exemplars (prototypic members of a phonetic category) to behave as perceptual magnets, interest has shifted toward peripherality, with the edges of the vowel space being considered as perceptual anchors[1]. Therefore, discrimination would be easier when the more peripheral[2] vowel in a pair is presented in second position. In this case, the encoding of V1 (first vowel in terms of temporal order) will not be masked by V2 (unless the POE is due to a retroactive contrast).

In previous studies, vowel continua are synthesized by fragmenting, in equidistant steps, the F1-F2 Euclidean distance in Hertz or Mel between exemplars of two distinct phonemic categories. Evidently, this method yields unrealistic intermediary sounds, inasmuch as most of them are assigned formant value combinations that cannot be produced by a human vocal tract due to articulatory/acoustic constraints (Boë et al., 1989). Furthermore, the fixed F3 and F4 values (3010 and 3300 Hz respectively) assigned to all members of the [i]-[e] continuum (upon which this paper focuses) generate a false spectral peak around 3000 Hz - a typical attribute for [i] in various languages [see Calliope (1989) for French, Hillenbrand *et alii* (1995) for American English]; [Spanish [i] and [e], on the other hand, appear to be similar (Quilis, 1983)]. Given that all stimuli in the continuum present an energy concentration in high frequencies, listeners would supposedly be induced to identify more /i/'s than they should, with the identification boundary shifting toward /e/.

In order to modify formants in a more realistic way, an articulatory model (Maeda, 1990) was selected. A model of this nature "offers the advantage of physiological realism by integrating articulatory constraints" (Boë *et alii*, 1989). By simultaneously modifying all 4 formants, listeners would be possibly inclined to use additional cues - such as spectral shape and energy concentration - during categorization and discrimination rather than merely use F1 and F2, as in the previous studies.

This paper consists in an extension of an earlier paper (Karypidis *et alii*, 2006), where data from French are presented. Our hypothesis then was that focalization plays a role in the asymmetry phenomenon due to focal[3] vowels' stability in short-term memory

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[1]It is possible that this shift of interest is due to the fact that practically every experiment in the literature where the POE is accounted for revealed that only one of the two categories spanning the various continua used behaves as an anchor which is not justified by the perceptual magnet hypothesis.

[2]A 'peripheral' vowel is characterized by an extreme formant value and is thus located on the edges of the vowel space. Whilst in almost all previous studies only F1 and F2 are explored, Best & Faber (2000) suggest that peripherality in F3 can also play a role (at least in the case of Norwegian /y/).

[3]Focal vowels are produced in specific regions in the vocal tract where formant affiliation switching occurs, causing two formants to come very close [for such quantal regions, see

(Schwartz & Escudier, 1989). In other words, we had suggested that the POE can be located in the pre-attentive (sensory) acoustic storage and has little – if none – to do with (long-term) memory categories established during exposure to a language.

In this article, we have replicated Experiments 1 and 2 of Karypidis *et alii* (2006) for three additional systems - Brazilian Portuguese, Spanish and Salentinian Italian - in order to explore a secondary factor, linguistic experience. Given that not all systems need base their /i/-/e/ contrast on F2' (Delattre *et alii*, 1952) or overall spectral envelope differences, if the POE is indeed linked to linguistic experience and to the functional status of a specific acoustic cue (in our case, F2') in a system, it would probably not be accounted for in a system which does not exploit F2' to contrast these two linguistic units. The choice of the four systems in question was therefore not random: French and Brazilian Portuguese have four distinctive vowel heights, whilst Spanish and Salentinian Italian only three. We have thus speculated that, in a system where the front vowel axis is busy (more than three heights), F1 and F2 differences between neighbouring vowels are not sufficiently important and listeners are inclined to use additional cues, such as F2' and spectral envelope in order to differentiate vowels belonging to the same natural class (front vowels). In this logic, order effects would be expected only for the first two systems and not for the two latter.

Two experiments were conducted. In Experiment 1, listeners classified the ten steady-state stimuli of the continuum as /i/ or /e/. This allowed us to verify whether sensitivity to F2' jumps is linked to a psychoacoustic process or to linguistic experience. In Experiment 2 (a slightly altered roving AX discrimination task), listeners discriminated between pairs of tokens differing in one or two steps along the continuum.

3. EXPERIMENT 1

3.1 Method

In this experiment, the listeners identified the ten tokens as /i/ or /e/ in an isolated context. The aim of this test was to verify whether listeners perceive the continuum in a linear or a discrete way (which could potentially constitute an indication that F2' is a criterion in decision making).

3.1.1 Subjects

Language	N	Range	M	SD
Brazilian Portuguese (BrP)	20	20-27	24	1.8
French (Fr)	34	18-51	31	9
Southern Salentinian Italian (SSI)	22	20-33	28	3.1
Spanish (Sp)	30	20-53	29	8.5

Table 1. Number (N) of listeners per language, Range of age, mean (M) age and standard deviation (SD).

Stevens (1972); Stevens (1989)]. In this paper, F2' estimation serves as a method to measure focalization.

In total, 106 listeners from four languages[4] participated in this experiment. All reported being native speakers and having no known hearing or speech impairments. Further details are available in Table 1.

3.1.2 Stimuli

Stimuli were as described in Experiment 1 of Karypidis *et alii* (2006). Maeda's (1990) articulatory model, VTCALCs, proposes a vocal tract configuration for each French vowel which the author of the model has chosen among many, based on its articulatory, acoustic and perceptual resemblance to its respective category. Table 2 indicates that the [i] and [e] configurations (tokens no 1 and 10 of our continuum, respectively) proposed by VTCALCs differ only in their Jaw Height and Tongue Position.

No of stimulus	Jaw height	Tongue position	Tongue shape	Apex position	Lip height	Lip protrusion	Larynx
1	0.5	-2	1	-2	1	-1	0
2	0.444	-1.88	1	-2	1	-1	0
3	0.388	-1.77	1	-2	1	-1	0
4	0.332	-1.66	1	-2	1	-1	0
5	0.276	-1.55	1	-2	1	-1	0
6	0.22	-1.44	1	-2	1	-1	0
7	0.164	-1.33	1	-2	1	-1	0
8	0.108	-1.22	1	-2	1	-1	0
9	0.052	-1.11	1	-2	1	-1	0
10	0	-1	1	-2	1	-1	0

Table 2. Articulatory parameters for the ten synthesized stimuli. Values correspond to standardized values.

The eight intermediary stimuli were prepared with stepwise linear interpolation of the parameter values in Table 2. In the continuum, stimulus 1 is the most extreme/peripheral (the most [i]-like) and stimulus 10 the lowest vowel (the most [e]-like). Formant extraction was performed using the Praat software (Boersma & Weenink, 2001)[5]. Given that F0 was not stable during the tokens (cf. infra), formant estimation over the whole stimulus - instead of around the mid-point - was preferred. The results are available in Table 3.

It should be noted that the two ends of the continuum do not necessarily constitute the prototypic exemplars of the two phonetic categories /i/ and /e/ in any of the four languages in question. We have simply used these two configurations in order to prepare a continuum where all formants would evolve simultaneously and which would span the two categories in question. In addition, it would also be possible to raise F1 of [i] (stimulus no 10) from 300 Hz to 400 Hz by only modifying Jaw Height. Nonetheless, the values given to this parameter would be completely unrealistic and similar to those of an [a].

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[4]Salentinian is a Romance dialect spoken along with Regional Italian (a five-vowel system as well) in Salento (Apulia). The term 'language' is loosely used here in the sense of 'system'.

[5]In Karypidis *et alii* (2006), we used VTCALCs' built-in function of formant extraction. Nonetheless, given that the input and output values may differ, an acoustic analysis of the output file seemed more prudent.

For all stimuli, fundamental frequency rose from 121 to 130 Hz over the first third and then declined to 100 Hz over the final two-thirds. Duration was fixed at 350 ms. The stimuli were synthesized at an 11025-Hz sampling rate and a 16-bit depth and were saved in mono .wav files and in PCM (Pulse Code Modulation) format. Before being submitted to the listeners, they were matched in RMS energy (at -10 dB) with Sound Forge 6.0.

	Hertz				Bark				
Token	F1	F2	F3	F4	F1	F2	F3	F4	F2'
1	249	2265	3122	3618	2.49	13.84	15.94	16.86	16.25
2	262	2248	3046	3635	2.63	13.79	15.78	16.89	16.15
3	276	2229	2937	3667	2.78	13.74	15.55	16.94	16.01
4	291	2206	2831	3698	2.94	13.67	15.31	16.99	14.22
5	306	2182	2752	3720	3.09	13.59	15.13	17.03	14.11
6	322	2156	2686	3728	3.25	13.51	14.97	17.04	14.00
7	337	2126	2638	3738	3.40	13.42	14.85	17.06	13.90
8	352	2095	2596	3738	3.55	13.32	14.75	17.06	13.80
9	365	2061	2563	3743	3.68	13.21	14.66	17.07	13.70
10	378	2024	2529	3733	3.80	13.09	14.57	17.05	13.59

Table 3. Formant values (F1–F4) in Hertz and Bark for the ten synthesized stimuli.

3.1.3 Procedure

The tokens were presented binaurally over headphones in small, quiet rooms and the experiment was run on different laptops by the last four authors. An approximate sound-pressure level (around 70 dB SPL) was chosen intuitively in order for the tokens to give a quasi-realistic impression and was identical for the participants of each language (given the differences in sound cards, it is possible that the intensity was slightly different for each language group). Praat served as the interface of the experiment. Stimuli were presented in seven blocks (7 repetitions x 10 stimuli) with the 'PermuteBalancedNoDoublets' randomization strategy (the presentation was balanced between blocks and consecutive repetitions of the same stimulus were avoided).

Two answers were proposed, <i> and <é> for Fr, <i> and <e> for Sp, SSI and BrP listeners. In order to be certain that Fr and BrP listeners realized that the second symbol corresponded to the mid-close (/e/) and not the mid-open (/ɛ/) front vowel, oral explanations and examples were given in the beginning of the experiment. The two alternatives were presented on the screen in large, yellow squares, upon which listeners were asked to click. After each response, the following stimulus was presented with a 500-millisecond delay. A break was offered every 20 stimuli and listeners were requested to click anywhere on the screen to continue. Most listeners clicked through this screen message almost instantly, indicating that the experiment was not cumbersome (approximate total duration: 4 minutes).

The experiment was preceded by a short training session containing two experimental blocks.

3.2 Results - Discussion

A binomial test (Uitenbroek, 1997) for each language showed that identification scores for all tokens (except token 5 for Spanish listeners) were above chance level (α=0,01).

A repeated-measures ANOVA revealed a significant effect of the factor 'stimulus' [F(9,171)=256,04, p<,001 for BrP; F(9,297)=462,28, p<,001 for Fr; F(9,198)=386,97, p<,001 for SSI; F(9,261)=578,03, p<,001 for Sp]. Identification curves for the four languages are available in Figure 1.

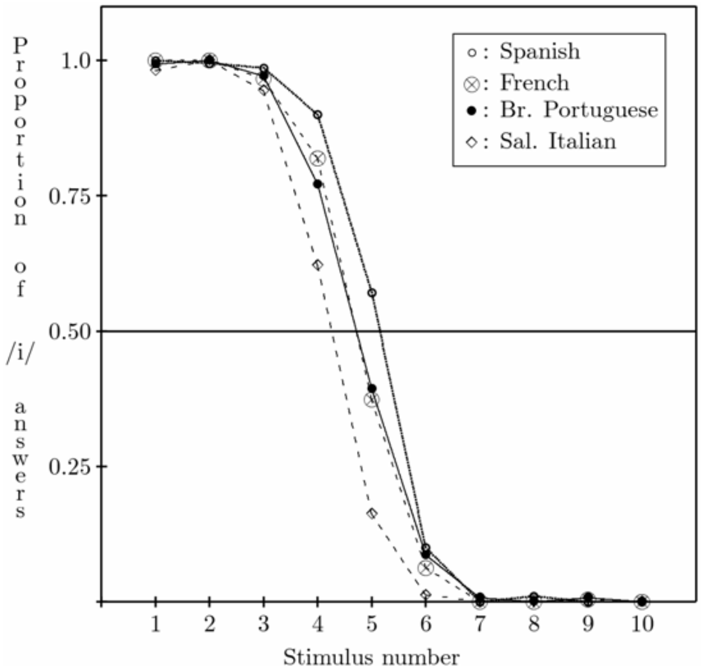

Figure 1. Identification curves for the four languages.

Figure 1 indicates that the transition from /i/ to /e/ is highly discontinuous, whilst the articulatory parameters entered in the model (Table 2) and the formant evolution (Table 3) are linear. This non-linear relation articulatory input/acoustic output and perceptual encoding agrees with Stevens' (1989) claim that in certain regions of the vocal tract, abrupt changes occur on the articulatory, acoustic or perceptual level whilst the manipulation of the other two parameters is linear.

In order for the nature of this quantal relation to be better understood, F2' values (see Introduction) were estimated for the ten stimuli. Raw values (in Hertz) had to be converted into Bark scale before being entered in the formula. This was achieved using Traunmüller's (1990) formula:

$$z= (26.81)/((1+1960)/f) - 0.53 \qquad (1)$$

where f stands for 'frequency' (in Hertz) and z for 'critical band rate z' (in Bark).

Results (Table 3, last column) indicate that the cut-off point estimated by F2' (that is, between stimuli 3 and 4) does not correspond to the actual identification boundaries found in Figure 1. Therefore, if F2' is indeed a psycho-acoustically valid measure, it seems that quantal regions are more flexible than what an integrative model (upon which F2' estimation is based) would suggest. Thus, a whole-spectrum perception model (Zahorian & Jagharghi, 1993) would possibly provide a better explanation for the differences in phoneme boundaries across languages given its flexibility (precise formant extraction is not needed).

4. EXPERIMENT 2

The experiment consisted of a roving AX discrimination task, where the stimuli of Experiment 1 were presented in pairs and in both orders, while differing in 1 or 2 steps along the continuum. The aim of this study was to examine whether the order effect would be accounted for only when focal or extreme tokens are concerned and only for certain languages.

4.1 Method

4.1.1 Subjects

In total, 96 individuals from the general pool participated in this experiment.

4.1.2 Stimuli

Stimuli were as described in Experiment 1.

4.1.3 Procedure

External conditions were as described in Experiment 1. Listeners were presented with 5 blocks of 18 one-step pairs (9 token combinations x 2 orders) and 16 two-step pairs (8 token combinations x 2 orders) with the 'PermuteBalancedNoDoublets' randomization strategy. When in a pair, the first stimulus presented is more extreme (lower F1, higher F2) than the second, the order is considered to be Forward. In the Reverse order, the more extreme token is presented second. Pairs of identical tokens were not presented due to time constraints[6]. All stimulus combinations are available in Table 4.

Group of pairs	Order	Step difference	Label	N of pairs
1-2, ..., 9-10	Forward	One	For_1	9
2-1, ..., 10-9	Reverse	One	Rev_1	9
1-3, ..., 8-10	Forward	Two	For_2	8
3-1, ..., 10-8	Reverse	Two	Rev_2	8

Table 4. The four groups of stimulus pairs and their characteristics: order, step difference along the continuum, label (the way the group is referred to throughout this paper) and number of pairs in the group.

The Inter-Stimulus Interval (ISI) was fixed at 250 ms. Subjects were asked whether vowels in each pair were absolutely identical or different. After each answer, the first vowel of the following pair was presented with a 0.5-second delay. The experiment was interrupted every 15 pairs of stimuli[7], proposing a short break and asking listeners to click anywhere on the screen to continue.

[6]Results from an additional experiment, including identical pairs, revealed that the POE is resistant

[7]The optimal solution would be to introduce pauses at the end of each presentation block but pre-tests showed that listeners needed a pause in-between.

The experiment was preceded by a short training session containing an experimental block.

4.2 Results - Discussion

Our main hypothesis predicts that mean discrimination scores for pairs where the most peripheral element is presented first (Forward order) would be lower than those for pairs in the reverse order (Reverse order).

Factor	Language	**df**	**F**	**p**
Order	Fr	1,32	11,801	,005
	SSI	1,14	25,895	,001
	BrP	1,19	0,199	,66
	Sp	1,27	3,173	,086
Pair	Fr	8,256	9,038	,001
	SSI	8,112	11,817	,001
	BrP	8,152	20,781	,001
	Sp	8,216	15,495	,001
Pair*Order	Fr	8,256	4,578	,001
	SSI	8,112	5,068	,001
	BrP	8,152	,458	,884
	Sp	8,216	1,174	,091

Table 5. Results of ANOVA with repeated measures on two factors - Order and Pair - for one-step condition. Df= Degree of Freedom.

An ANOVA with repeated measures on both factors, Pair and Order, yielded a significant effect of Order for Fr and SSI listeners in both conditions (one- and two-step) but not for BrP or Sp for either condition. The effect of Pair was significant for all four languages and in both conditions. The Order*Pair interaction was significant for Fr and SSI in the one-step condition and for Fr and Sp in the two-step condition. Detailed results are available in Tables 5 and 6 (one-step and two-step condition respectively).

Factor	Language	**df**	**F**	**p**
Order	Fr	1,32	14,484	,001
	SSI	1,14	7,259	,05
	BrP	1,19	,353	,559
	Sp	1,27	,273	,605
Pair	Fr	7,224	20,468	,001
	SSI	7,98	20,161	,001
	BrP	7,133	35,981	,001
	Sp	7,189	24,765	,001
Pair*Order	Fr	7,224	9,124	,001
	SSI	7,98	1,215	,302
	BrP	7,133	1,469	,184
	Sp	7,189	3,497	,001

Table 6. Results of ANOVA with repeated measures on two factors - Order and Pair - for two-step condition.

A graphic representation of scores for each pair gives us a better insight. In Figure 2, it is rather clearly seen that in the two languages where the asymmetry effect occurs in a systematic way, French and Salentinian Italian, the pairs contributing to POE are those containing an /i/-like vowel (according to identification results). This could be justified by various factors:

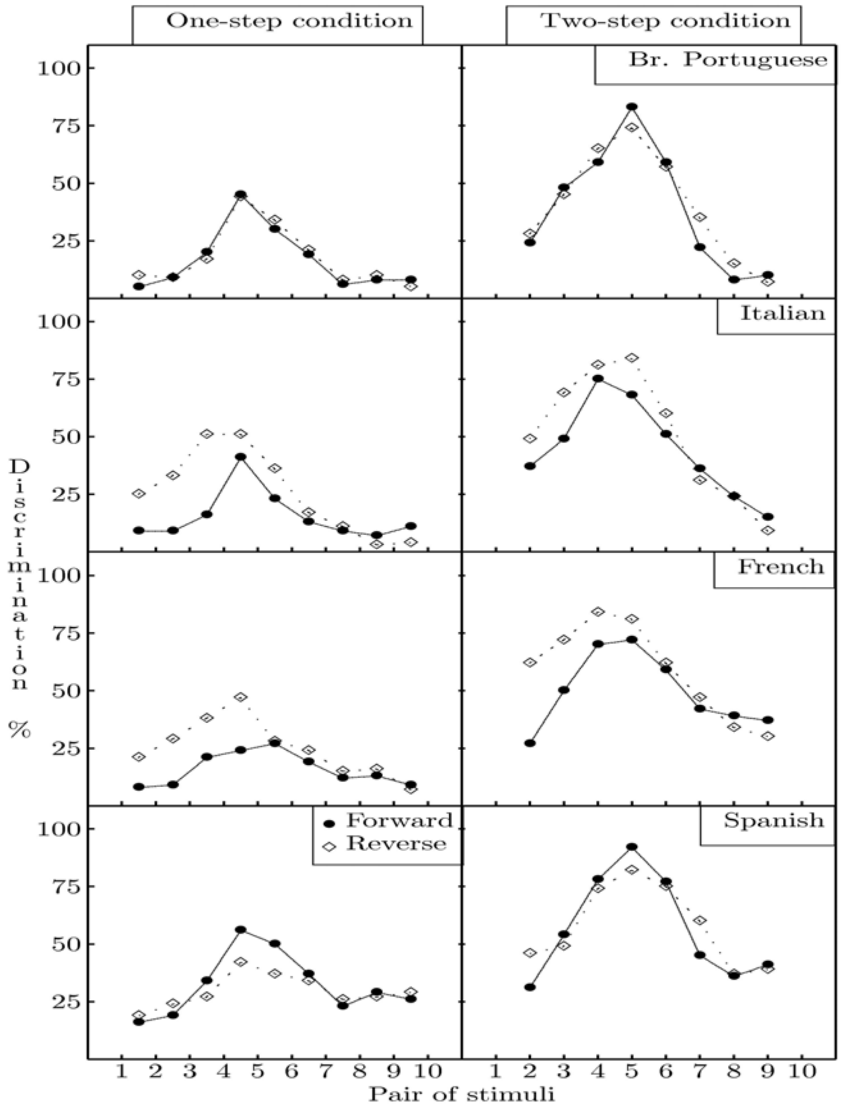

Figure 2. Discrimination functions for the four languages. On the horizontal axis, the pair of stimuli. In the two-step condition (right column), points represent the scores (in percentages) for the pair containing the stimuli n-1 and n+1. Scores for pairs in the Forward order are represented with empty diamonds and in the Reverse order with full circles.

- *Acoustics + linguistic experience.* The stimuli in question behave as perceptual anchors because they are located around the corner and on the periphery of the vowel space. Meunier *et alii*'s (2003) data show that the periphery (on the F1-F2 plane) of the space covered by French vowels and that covered by Spanish vowels do not correspond (French vowels are higher and more posterior). Therefore, it is possible that POE would occur only in those languages where the stimuli presented in the task are more peripheral than the listeners' native vowels or simply on the outer side of the listeners' native vowel space. An acoustic study of the four languages studied here would be rather compelling. On the other hand, based on Meunier *et alii*'s (2003) suggestion that the size of a vowel space does not depend on the density of the system, we would not be able to predict in which languages the asymmetry effect would be accounted for.
- *Encoding + long-term memory*. Proactive/retroactive[8] contrast based on labelling is stronger in the case of /i/. In this case, POE would not be located on the pre-attentive, sensory-trace level but would rather be a consequence of linguistic processing, using memory categories pre-existing in long-term memory. However, this would still not explain why POE is not common to all listeners.
- *The functional/cognitive status of F2' in a system*. The notion of F2' is directly linked to integrative models (Chistovich & Lublinskaja, 1979), where formants that are close together on the spectrum are perceived as one single frequency peak. Such vowels tend to stay longer in short-term memory (Schwartz & Escudier, 1989). In our continuum, there were three focal vowels, i.e. stimuli no 1-3. Thus, this persistence of focal vowels in memory could explain the POE but not why it is only encountered in French and Salentinian Italian. In order to clarify this supposable inconsistence, it suffices to revisit literature for prototypic formant values in the four languages in question. Therefore, it appears that in French (Calliope, 1989) and Salentinian Italian (Costagliola, 2005), the difference in F2' between [i] and [e] is considerable, whilst in Spanish these two categories present a quasi-equal F2' (Quilis, 1983). We are not aware of F3 values for Brazilian Portuguese. This would indicate that in the first two languages, F2' is indeed used in order to contrast the two sounds in question, which would in turn, suggest that when, in a language, F2' (or focalization) is not used as a contrasting cue (the case of Spanish and, by deduction, Br. Portuguese), discrimination is not based directly on differences in F2'. Evidently, this hypothesis would be more appropriately examined if one was to vary the Interstimulus Interval so as to verify whether memory loss for focal vowels occurs in the same way for languages that do or do not use F2' as a perceptual cue.

5. CONCLUSION

In this paper, we have revisited our theory (formulated in Karypidis *et alii*, 2006) according to which the presentation order effect is triggered by vowels located on the periphery of the F1-F2' plane. Four systems were examined: French, Southern Italian (Salentinian), Brazilian Portuguese and Spanish. Results revealed asymmetries only around the /i/-like endpoint of our continuum, which concurs with our hypothesis. Nonetheless, the lack of asymmetry for Spanish and Brazilian Portuguese forced us to reformulate the initial

[8] It is still not clear whether the order effect is due to a proactive or a retroactive contrast. Nonetheless, this is a separate issue with which we do not deal in this paper. For a closer study of the preeminence of retroactive or proactive contrast, see Shigeno & Fujisaki (1980), Repp *et alii* (1979) and Cowan & Morse (1986).

hypothesis, this time by examining the potential linguistic/cognitive role that F2' could play in a system: "Presentation order effects are triggered by focal vowels, located on the periphery of the F1-F2' space, if and only if F2' plays a functional role in the system in question.".

Evidently, in order for our revisited postulate to be more closely examined, listeners from various languages would have to be included. In addition, a crucial issue needs to be addressed: are order effects due to primacy or recency effects? A discrimination task where the ISI would be systematically varied would offer an adequate response to this question; this would allow us to understand whether the POE is linked to a phonetic labeling or is located in the short-term memory.

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