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Hemispheric predominance assessment of phonology and semantics: A divided visual field experiment

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Abstract

The aim of the present behavioural experiment was to evaluate the most lateralized among two phonological (phoneme vs. rhyme detection) and the most lateralized among two semantic ("living" vs. "edible" categorization) tasks, within the dominant hemisphere for language. The reason of addressing this question was a practical one: to evaluate the degree of the hemispheric lateralization for several language tasks, by using the divided visual presentation of stimuli, and then choose the most lateralized semantic and phonological for mapping language in patients by using fMRI in future studies. During the divided visual field experiment by using words (semantic tasks) and pseudo-words (phonological tasks) as stimuli, thirty-nine right-handed participants were examined. Our results have shown that all tasks were significantly left hemisphere lateralized. Furthermore, the rhyme was significantly more lateralized than phoneme detection and "living" was significantly more lateralized than "edible" categorization. The rhyme decision and "living" categorization will be used in future fMRI studies for assessing hemispheric predominance and cerebral substrate for semantics and phonology in patients. Our results also suggest that the characteristics of stimuli could influence the degree of the hemispheric lateralization (i.e., the emotional charge of stimuli for words and the position of the phoneme to be detected, for pseudo-words).

Keywords: Semantic; Phonology; Divided visual field; Rhyme; Categorization; Phoneme detection; Healthy subjects

1. Introduction

The concept of hemispheric specialization (predominance, lateralization) for language means that one hemisphere is predominantly involved in language activities, with respect to the other one (Josse & Tzourio-Mazoyer, 2004). Ninety percent of people have the left hemisphere predominant for language (Cubelli & Montagna, 1994; Finger & Roe, 1996; Tzourio-Mazoyer, Josse, Crivello, & Mazoyer, 2004). The hemispheric specialization for language is relative, although one hemisphere is predominant for language, the other one could also be involved (Jung-Beeman, 2005; Mitchell & Crow, 2005). The degree of lateralization depends on several variables such as gender (Shaywitz et al., 1995; Vikingstad, George, Johnson, & Cao, 2000), handedness (Eviatar, Hellige, & Zaidel, 1997; Knecht et al., 2000; Knecht & Drager et al., 2000), and language tasks used for assessing specialization (Burton, Locasto, Krebs-Noble, & Gullapalli, 2005; Engstrom, Ragnehed, Lundberg, & Soderfeldt, 2004). For instance, it has been shown that the phonological aspect of language is more lateralized than the semantic one (Baciu et al., 2001; Bahn et al., 1997; Kareken, Lowe, Chen, Lurito, & Mathews, 2000). Furthermore, the degree of lateralization would depend on the type of semantic or the type of phonological task.

One of situations requiring the assessment of the predominant hemisphere for language is the pre-surgical mapping in epileptic patients before surgery. Within this framework, the choice of language tasks to be used is an essential point. The tasks to be used should: (a) induce strong lateralization within the dominant hemisphere and (b) map essential language operations, such as phonology and semantics. Previous

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neuroimaging studies have shown that semantic and phonological processes activate a large network including frontal, temporal, and parietal regions. Some of them are specifically activated for phonology and others for semantics (for a review see Vigneau et al., 2006). It means that at least semantic and phonological tasks should be used in patients for mapping language. Although we did not explored in this study the cerebral substrate for semantics and phonology while we have performed a behavioural experiment, we briefly remind the cerebral regions specifically activated for semantics and for phonology. Within the dominant hemisphere, the inferior frontal (BA 47) (Poldrack et al., 1999), inferior and middle temporal (BA 37, 21) (Billingsley, McAndrews, Crawley, & Mikulis, 2001), and inferior parietal (angular gyrus, BA 39) (Price, 2000), regions are classically activated during semantic tasks, while the inferior frontal (BA 44, 45) (Poldrack et al., 1999, 2001), superior temporal (BA 22) (Billingsley et al., 2001), and inferior parietal (supramarginal gyrus, BA 40) (Gitelman, Nobre, Sonty, Parrish, & Mesulam, 2005) regions are classically activated during phonological tasks. During the present experiment, we have tested two phonological tasks (rhyme decision/detection and phoneme detection) and two semantic tasks (living categorization and edible categorization). The choice of these tasks was based on their classical use in neuroimaging studies in healthy subjects (Demonet et al., 1992; Seghier et al., 2004; Simon, Mangin, Cohen, Le Bihan, & Dehaene, 2002; Tieleman et al., 2005) or patients (Baciu et al., 2001; Billingsley et al., 2001; Binder et al., 1996).

The dominant hemisphere for language could be assessed by using behavioural procedures such as the divided visual field experiment (Channon, Schugens, Daum, & Polkey, 1990; Chiarello, Kacinik, Manowitz, Otto, & Leonard, 2004; D'Hondt & Leybaert, 2003; Tremblay, Monetta, & Joanette, 2004) and the dichotic listening (Bradshaw, Burden, & Nettleton, 1986; Fernandes & Smith, 2000; Helland & Asbjornsen, 2001). A widely used approach in behavioural experiments for determining the hemispheric specialization is the divided visual field (DVF) procedure. It consists of presenting stimuli very briefly (<150 ms) to the left (i.e., the left visual field, LVF) or to the right (i.e., the right visual field, RVF) with respect to a central fixation cross. This technique is based on the characteristic of visual pathways, to be completely crossed and on the controlaterality rule of the vision. It means that a stimulus presented in one hemifield (LVF vs. RVF) is processed first by the opposite hemisphere (RH vs. LH, respectively). The stimulus is processed faster and better if it is presented first to the specialized hemisphere. This experimental technique was used in a limited number of studies for assessing language lateralization (D'Hondt & Leybaert, 2003; Tremblay et al., 2004).

The aim of this divided visual field experiment was to evaluate the most lateralized among two phonological (phoneme detection vs. rhyme detection) and the most lateralized among two semantic ("living" categorization vs. "edible" categorization) tasks. Our hypothesis was that the language task depending on the left specialized hemisphere will be performed significantly more accurately when stimuli are presented first in the RVF. Furthermore, the most lateralized among the two semantic and the most lateralized among the two phonological tasks, will induce the greatest difference between visual fields.

2. Material and methods

2.1. Participants

Thirty-eight healthy male participants (mean of age 21.7 years old), native French speakers, were recruited. They all were right-handed according to the Edinburgh Handedness Inventory (Oldfield, 1971) and had normal or corrected-to-normal vision.

2.2. Stimuli

During the *rhyme detection task*, the stimuli were French pseudo-words. We have used 96 legal pseudo-words, displayed randomly, 48 in the LVF and 48 in the RVF. Each item was composed of seven letters. Half of items rhymed with /é/. The frequency of the three orthographical shapes é (i.e., compuré), *er* (i.e., barli**er**), and é*e* (i.e., grompé**e**) of the phoneme /é/ has been counterbalanced in order to neutralize a possible skew related to orthographic visual representation. During the *phoneme detection task*, the stimuli were pseudo-words. We have used 96 legal pseudo-words displayed randomly, 48 in the LVF and 48 in the RVF. Each item was composed of seven letters. Half of items contained the phoneme /b/. This phoneme was placed an equivalent number of times at the beginning (i.e., **b**aville) in the middle (i.e., cha**b**iot) or at the end (i.e., sala**b**ié) of the pseudo-words. During *"living" and "edible" categorization tasks*, the stimuli were represented by medium and high frequency French words extracted from *Brulex* database (Content, Mousty, & Radeau, 1990). For each task we have used 96 words displayed randomly (48 in the LVF and 48 in the RVF), composed of six letters each. During the "living" task, half of items designed plants and animals and half designed objects. During the "edible" task, half of items designed ingredients and food and half designed objects.

All linguistic stimuli were written in "Courrier New" size 24. Each item was presented for 130 ms, shorter than a saccade, for assuring the mono-hemispheric presentation. For each task, we have built different lists presented randomly among participants. During each task, each item was followed by a *mask* similar to a non-word composed of unreadable characters (stars). The mask (30 ms duration) was used in order to avoid the retinal persistence. Also, during each task, a *control item* was presented 96 times. The control item was a red rectangle which has the same length as the longest linguistic stimulus. The item control involves low-level visual processes which should not be hemispheric lateralized. The use of control items allowed checking that inter-hemispheric differences are not due to visual processing but to linguistic activity.

2.3. Tasks and procedure

The "phonological session" was composed of *phoneme detection* and *rhyme detection* tasks, while the "semantic session" was composed of "*living*" categorization and "*edible*" categorization tasks. During *rhyme detection* subjects were asked to judge whether pseudo-words rhymed with /é/. During *phoneme detection* subjects were asked to judge whether pseudo-words contained the phoneme /b/. During "*living*" and "*edible*" categorization tasks subjects were asked to judge whether words belong to "plants" and "animal" categories, or to "ingredient" and "food" categories, respectively. For each task, during the presentation of the control item, participants were instructed to simply respond when they detected the red rectangle. For each task, a *go/nogo* procedure was used. The duration time of each task was 12 min. The duration time for each participant examination (phonological and semantic sessions) was 55 min.

Each participant was tested individually in a darkened quiet room. They were seating in front of a computer monitor (screen resolution 1024 by 768 pixels) located 110 cm from them. The experiment was built by using the E-Prime software (E-Prime Psychology Software Tools Inc., Pittsburgh, USA). Each trial began with a fixation cross (in order to keep the gaze direction at the centre of the screen) during 500 ms. Then, a stimulus was displayed either in the LVF or in the RVF during 130 ms. Each item has been followed by a mask presented during 30 ms. The inner and the outer edges of these lateralized stimuli subtended a visual angle of 2° and 6° off centre, respectively. Finally, the trial ended with a fixation cross during 1500 ms. Subjects were instructed to press a response button (located in the sagittal plane), each time and only (*go/nogo* response) when the stimulus rhymed with /é/ (rhyme detection), contained the phoneme /b/ (phoneme detection), designed plants or animals (living categorization) and designed ingredients or food (edible categorization). Also, the participants gave responses each time when they detected a red rectangle. Half of participants responded with the right index finger, the other half responded with the left index finger. Before each trial, participants underwent a short training session composed of items not presented during the trial.

3. Results

All results are presented in terms of accuracy (% Correct Responses, CR). We do not present results in terms of response time (RT) because data was poor given that participants gave responses only for "*go*" condition. Correct Responses Rates (% CR) for each condition are reported in Table 1. We did not obtain difference of performance between tasks, suggesting that all had the same level of difficulty. A $2 \times 2 \times 2$ ANOVA per participants (F_1) was performed on % CR with three conditions (Visual field of presentation vs. Tasks vs. Response hand) as within-subjects factors. Overall, our results showed that phonology and semantics are left hemisphere lateralized. Furthermore, rhyme was more lateralized than phoneme detection, as well as "living" was more lateralized than "edible" categorization.

Table 1
The mean of Correct Responses Rates (% CR) for stimuli presented within the left visual field (LVF) and right visual field (RVF) for each task

Phonological detection tasks				Semantic categorization tasks			
Phoneme		Rhyme		"Living"		"Edible"	
LVF	RVF	LVF	RVF	LVF	RVF	LVF	RVF
68.09%	73.08%	62.34%	80.48%	57.95%	73.79%	59.16%	69.13%

3.1. Phonological session

We obtained a significant effect of the visual field of presentation [$F_{1(1,37)} = 123.18$, MSe = 0.082, $p < .0001$] but no significant effect of task [$F_{1(1,37)} = 0.662$, MSe = 0.077, $p = .42$]. Participants were significantly more accurate for items presented in the RVF (77%) than LVF (51%). In addition, significant interaction between task and visual field [$F_{1(1,37)} = 34.57$, MSe = 0.095, $p < .0001$] was obtained, suggesting that the inter-hemispheric difference during performing rhyme was significantly greater then during performing phoneme detection (Fig. 1). We did not obtain significant effect of the response hand [$F_{1(1,37)} = 0.008$, MSe = 0.021, $p = .92$].

In order to evaluate the possible effect of the position of the phoneme target (phoneme to be detected) on the hemispheric lateralization, we conducted a 2×3 analysis on the % of correct responses for phoneme detection task with two conditions, *Visual field of presentation* (RVF vs. LVF) vs. *Phoneme position* (initial, middle, and end) as within-subjects factors. Based on this analysis, we obtained an effect of the target position [$F_1(1,74) = 57.53$, MSe = 0.049, $p < .0001$] and of the visual field of presentation [$F_1(1,37) = 12.52$, MSe = 0.064, $p < .01$]. Subsequently, the interaction performed between visual field and target position was signifi-

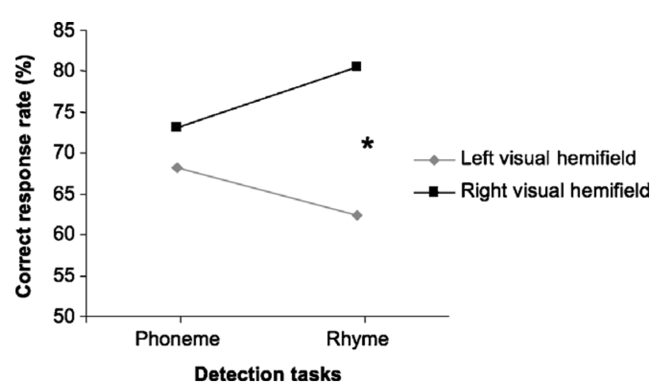

Fig. 1. In terms of accuracy (% CR), the interaction between the visual field and phonological tasks (rhyme and phoneme detection) for stimuli presented in left (grey) and right (black) visual hemifield. Although both tasks induced a significant advantage of the RVF (LH), the inter-hemispheric difference is significantly greater ($p < .0001$) during the rhyme than during phoneme detection.

cant [$F_1(1,74) = 21.10$, $MSe = 0.023$, $p < 0.0001$]. No significant effect on accuracy between visual fields was obtained for the initial [$F_1(1,37) = 0.24$, $MSe = 0.013$, $p = .62$] and the middle [$F_1(1,37) = 2.09$, $MSe = 0.046$, $p = .15$] positions but significant effect was obtained for the end position [$F_1(1,37) = 33.40$, $MSe = 0.05$, $p < .0001$] with higher accuracy for pseudo-words presented in the RVF with respect to the LVF, as during the rhyme detection task (rhyme always at the end).

3.2. Semantic session

We obtained a significant effect of the visual field [$F_{1(1,37)} = 87.98$, $MSe = 0.0143$, $p < .0001$] but no effect of task [$F_{1(1,37)} = 2.52$, $MSe = 0.0089$, $p = .121$]. Participants were significantly more accurate for items displayed in the RVF (71%) than in the LVF (58%). In addition, significant interaction between task and visual field [$F_{1(1,37)} = 8.55$, $MSe = 0.0076$, $p < 0.05$] was obtained, suggesting that the inter-hemispheric difference during performing "living" was significantly greater than during performing "edible" categorization (Fig. 2). We did not obtain significant effect of the response hand [$F_{1(1,37)} = 0.0067$, $MSe = 0.015$, $p = .93$].

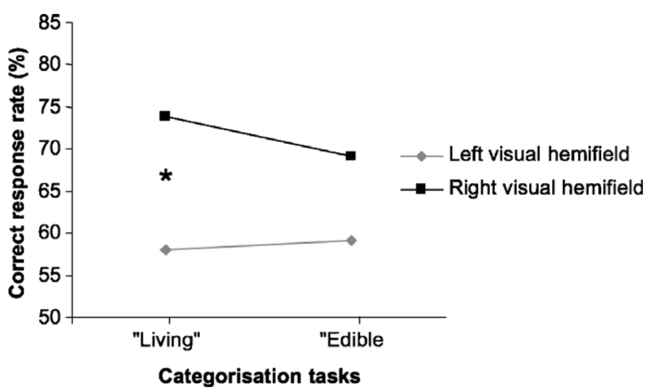

Fig. 2. In terms of accuracy (% CR), the interaction between the visual field and semantic tasks ("living" and "edible" categorization) for stimuli presented in left (grey) and right (black) visual hemifield. Although both tasks induced a significant advantage of the RVF (LH), the inter-hemispheric difference is significantly greater ($p < .01$) during the "living" than during "edible" categorization.

Although the performance was generally poor during phonological and semantic tasks, as mentioned previously, t tests performed between each condition against the chance level showed that our results were significantly above the chance level (Table 2 for phonological tasks and Table 3 for semantic tasks).

In addition, we assumed that the degree of the hemispheric lateralization for our tasks should be related only to the visual field of presentation and not to the difficulty of items. All items presented during categorization tasks were medium and high-frequency words, counterbalanced between visual fields. Furthermore, all participants had a high educational level. Thus, it was very unlikely that differences in lateralization during categorizing living and categorizing edible entities were induced by some difficult items. To check this assumption, we conducted an analysis of variance per items (F_2), one for the phonological session and another one for semantic session. These analyses have reproduced the results presented previously. During semantic session, we obtained an effect of the visual field of presentation with significant predominance of the RVF LH [$F_{2(1,184)} = 68.29$, $MSe = 0.034$; $p < 0.0001$]. The interaction between visual field of presentation and task was significant [$F_{2(1,184)} = 9.08$, $MSe = 0.034$; $p < .001$] with greater inter-hemispheric difference during performing "living" than during performing "edible" categorization. The effect of task (type of item) was not significant [$F_{2(1,184)} = 0.82$, $MSe = 0.034$; $p > .1$]. During phonological session, we obtained an effect of the visual field of presentation, with significant predominance of the RVF LH [$F_{2(1,184)} = 25.87$, $MSe = 0.049$; $p < 0.0001$]. The interaction between visual field of presentation and task was significant

Table 2

Statistical values for the contrast (t test) performed for each condition against the chance level during phonological tasks (LVF = left visual field, RVF = right visual field, LH = left hemisphere, and RH = right hemisphere)

	Phoneme detection				Rhyme detection			
	LVF RH	LVF LH	RVF RH	RVF LH	LVF RH	LVF LH	RVF RH	RVF LH
Mean	0.66	0.70	0.74	0.72	0.63	0.61	0.80	0.81
SD	0.08	0.09	0.10	0.11	0.12	0.11	0.09	0.10
t test	11.99	14.39	14.52	12.82	6.89	6.47	21.46	18.84
p	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<0.0001

Table 3

Statistical values for the contrast (t test) performed for each condition against the chance level during semantic tasks (LVF = left visual field, RVF = right visual field, LH = left hemisphere, and RH = right hemisphere)

	"Living" categorization				"Edible" categorization			
	LVF RH	LVF LH	RVF RH	RVF LH	LVF RH	LVF LH	RVF RH	RVF LH
Mean	0.59	0.57	0.74	0.74	0.58	0.60	0.69	0.69
SD	0.11	0.09	0.12	0.12	0.11	0.10	0.13	0.10
t test	4.84	4.90	12.06	11.91	4.84	6.17	8.77	11.56
p	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<0.0001

[$F_{2(1,184)} = 8.36$, MSe = 0.049; $p < .001$] with greater inter-hemispheric difference during performing rhyme than performing phoneme detection. The effect of task (type of item) was not significant [$F_{2(1,184)} = 0.55$, MSe = 0.049; $p > .1$]. Thus, the statistical analysis per items showed that differences between "living" and "edible", as well as between rhyme and phoneme detection, were not due to some difficult items.

We also performed a statistical analysis on data obtained during the control condition (red rectangle). We did not obtain significant effect of the visual field of presentation, neither during phonological [$F_{1(1,37)} = 0.20$, MSe = 3.18, $p = .65$] nor during semantic [$F_{1(1,37)} = 0.52$, MSe = 1.73, $p = 0.47$] sessions, thus no hemispheric predominance for this low level visual task. This result suggests that the predominance of the RVF LH obtained during semantic and phonological tasks was not due to low level perceptive effects but to high-level language processes.

4. Discussion

In the present study, we aimed at evaluating the most lateralized among two phonological and the most lateralized among two semantic tasks, by using the visual field presentation of stimuli. Our hypothesis was that although the left hemisphere should be predominant for all tasks as all participants were right-handed, the degree of lateralization should vary with task. Overall, our results showed that semantic and phonological tasks were left hemisphere lateralized because they were performed significantly more accurately when stimuli were presented first to the left hemisphere (RVF). This result is in agreement with previous studies using divided visual and dichotic listening procedures (Channon et al., 1990; Chiarello et al., 2004) and neuroimaging studies (Poldrack et al., 1999, 2001; Seghier et al., 2004).

With respect to phonological tasks, the rhyme was significantly more lateralized than the phoneme detection, as previous studies have shown, either by using words (Baciu et al., 2001; Bahn et al., 1997; Kareken et al., 2000; Seghier et al., 2004) or pseudo-words (Billingsley et al., 2001) as stimuli. The phoneme detection was less lateralized with stronger involvement of the right hemisphere. The weaker lateralization during this task could have several explanations. One of them is the particularity of this task. The visual phoneme detection examined in this study could be assimilated to a letter detection task. The target phoneme—/b/—has a high degree of grapho-phonemic transparency, meaning that its translation from orthography to phonology is regular (i.e., the sound /b/ is always corresponding to the letter b). Within this framework, Tremblay et al. (2004) suggested that processing transparent phonemes seems to require more the participation of two hemispheres by involving less the language regions with respect to bilateral visual regions responsible of low level not-lateralized perceptive processes. A bilateral non-linguistic activation during letter detection task has been previously shown. For instance, A PET study (Cappa, Perani, Schnur, Tettamanti, & Fazio, 1998) showed that letter detection activates poorly language regions and stronger striate and extra striate visual regions, bilaterally. The use of a non-transparent phoneme (like /o/), or performing the phoneme detection task in aural modality should increase the hemispheric lateralization by stronger involvement of language regions (Demonet et al., 1992). Another aspect explaining the weaker degree of lateralization during phoneme detection as explored in our study, could be the different localisation of the target phoneme (phoneme to be detected, /b/) within stimuli. We have chosen three positions of the target, in order to avoid subjects performing just a visual detection and not a language (phoneme) detection task. If the target phoneme is placed only at the end, subjects focus always the gaze and the attention on the end of the pseudo-word for detecting the target and they will not "scan" the whole linguistic stimulus. Although the rhyme is always at the end, the stimuli will always be "scanned" and pronounce internally in order to make the judgement on rhyme. Given that target phoneme has three positions (during phoneme detection) and the rhyme is always at the end (during rhyme decision), a more appropriate way for comparing the two phonological tasks, would have been the comparison between the percent of correct responses during rhyme and the percent of correct responses during phoneme detection only for pseudo-words with target phoneme located at the end. Such a statistical comparison was impossible to be done because of the weak number of pseudo-words presenting the target at the end (12 items in the right VF and 12 items in the left VF), while the number of pseudo-words during rhyme detection was three times higher. Our statistical analysis conducted for assessing the effect of target position during phoneme detection, indicated that the significant hemispheric lateralization (predominance of the RVF LH) obtained during this task, was obtained only for the pseudo-words with target located at the end. This result suggests that the hemispheric specialization during phoneme detection is basely due to judgements made on pseudo-words with the target positioned at the end. But as only one third of stimuli had the phoneme target at the end of pseudo-words, it could explain why the phoneme detection was less lateralized than the rhyme detection task.

With respect to semantic tasks, our results have shown that "living" was significantly more lateralized than "edible" categorization. This result is in agreement with those provided by other studies using categorization tasks (Billingsley et al., 2001; Gitelman et al., 2005; Hugdahl et al., 1999; Springer et al., 1999) or specifically "living" categorization (Seghier et al., 2004; Tieleman et al., 2005). A possible explanation for the weaker degree of lateralization obtained during "edible" categorization could be the emotional component induced by this task ("*I like*" or "*I do not like*" associated to decision-making on ingredients and food). This explanation is supported by a recent divided visual field experiment performed by Ortigue et al. (2004) using neutral and emotionally charged words. The authors showed RVF (left hemisphere) predominance independently of the emotional charge of words. Furthermore, the lateralization was weaker for emotional than for neutral words suggesting that emotional words engage more the right hemisphere than the neutral words.

The question to be asked is whether the difference in the degree of lateralization between tasks could be induced by some difficult items presented in some tasks and not in other ones. We assumed that the degree of the hemispheric lateralization for the evaluated tasks in this study should be related only to the visual field of presentation and not to the difficulty of items. For this reason, all items presented during categorization tasks were medium and high-frequency words. Furthermore, all participants had a high educational level. Thus, it would have been very unlikely that differences concerning the degree of lateralization between tasks are induced by some difficult items. For checking this aspect, an analysis of variance per items has been done. The results provided by this analysis showed that the difference between "living" and "edible" and the difference between rhyme detection and phoneme decision were not due to some difficult items.

Based on the results provided by this divided visual field experiment conducted in healthy subjects, we will use in future fMRI experiments for mapping language in epileptic patients, a rhyme decision for mapping phonology and a living categorization for mapping semantics. Furthermore, our results suggest that different characteristics of stimuli could influence the degree of the hemispheric lateralization (i.e., the emotional charge of stimuli for words or the position of the phoneme to be detected, for pseudo-words) and they should always be taken into account. The main limit of this study was the lack of RT measurements, given that we used a *go/nogo* procedure. The lack of RT measures does not allow making strong predictions on the hemispheric processing of the information, in accordance with the classical models, the direct access and the callosal transfer (Waldie & Mosley, 2000). During a new current divided visual field experiment, we are testing the same tasks by asking subjects to give responses for all stimuli (*yes* and *no* responses) and we will analyse data by taking into account both, RT and % of correct responses. We hope obtaining more robust results for explaining the hemispheric processing of the information according to the classical models mentioned above.

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