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Hemispheric asymmetries in bilinguals: Tongue similarity affects lateralization of second language

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ABSTRACT

It is known that the left hemisphere of the human brain is critical in understanding and producing spoken language, but it remains a topic of great interest determining the cerebral lateralization of multiple languages. The aim of this study is to examine the effects of similarity between languages on hemispheric asymmetry of bilingual brains.

The involvement degree of left and right hemisphere was examined during the processing of the first (L1) and second (L2) language in two different groups of bilinguals with English as L2. The first group consisted of German native speakers and the second group of Italian native speakers. Subjects from the two groups acquired L2 later in life (after the age of six) and had a comparable level of proficiency in second language comprehension. The functional lateralization was tested by a classical dichotic test with words in L1 and L2.

Dependent variables were number of responses associated to words presented at the left vs. right ear and reaction time. Results showed a significant right ear advantage (REA) for number of responses in both languages and in both groups. However, the REA for L2 (English) processing was stronger in the German group. Reaction times were significantly lower during L1 processing and showed a trend towards the results obtained with the number of response variable. This study provides neuropsychological evidence pointing to a different lateralization pattern in the elaboration of a same L2 if L1 comes from different linguistic roots.

1. Introduction

The phenomenon of cerebral hemispheric specialization of cognitive functions and abilities in the human brain is well known. The first discovered and thus oldest phenomenon of brain lateralization within these functions is language processing; in right handed monolinguals the left hemisphere is dedicated to language processing more than the right one (Gazzaniga, 1970; Hellige, 1993; Soares & Grosjean, 1981; Wada, Clarke, & Hamm, 1975). LH specialization for language is supported by functional magnetic resonance studies, as it was concluded that the majority of people are left-lateralized for language, approximately 96% of normal individuals among right-handed and 76% among left handed (Pujol, Deus, Losilla, & Capdevila, 1999). Furthermore, the studies on human auditory cortex have shown that the two sides are specialized; temporal changes are preferentially detected by left auditory cortical areas, whereas spectral features especially recruit right auditory cortical regions. The development of this left-right asymmetry may be interpreted as a strategy for better processing acoustic information in temporal and frequency domains, respectively (Brancucci, Babiloni, Rossini, & Romani, 2005; Brancucci, D'Anselmo, Martello, & Tommasi, 2008a; Zatorre, Belin, & Penhune, 2002).

Although there is broad consensus on the left sided bias for right handed monolinguals, less defined is the pattern of hemispheric lateralization in the bilingual brain and the perception of multiple languages. The review of Hull and Vaid (2007) tries to shed light on this issue, analyzing many studies that have investigated hemispheric asymmetries in the perception of multiple languages. They found that the main aspect in determining language lateralization was the age of onset of bilingualism; acquiring more than one language before the age of six determines the involvement of both hemispheres in both languages but acquiring a second language after the age of six determines left hemispheric specialization for both languages. Moreover, about

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late bilinguals, it was demonstrated that non-proficient subjects are more left biased than proficient bilinguals in both L1 and L2.

In recent years a number of studies using neuroimaging techniques have investigated the cortical localization of multiple languages. The picture they provided is not so clear: on the one hand a set of studies support an overlap of areas involved in the processing of first and second language (Briellmann et al., 2004; Chee et al., 1999; Klein, Zatorre, Milner, Meyer, & Evans, 1994; Klein, Milner, Zatorre, Zhao, & Nikelski, 1999; Klein et al., 2006; Yokoyama et al., 2006); on the other hand further studies demonstrate the involvement of distinct or partially distinct brain regions for L1 and L2 (Dehaene et al., 1997; Perani et al., 1996; Perani et al., 2003; Marian et al., 2007; Kim, Relkin, Lee, & Hirsch, 1997). The different patterns of activation discovered have been ascribed mainly to two factors regarding L2, i.e. age of acquisition and proficiency. Wartenburger et al. (2003), in a fMRI study, investigated the effects of age of acquisition using a syntactic and semantic judgment task in L1 and L2 in early and late bilinguals. They found that during grammatical processing in L2, late bilinguals show more extensive activation in Broca's area, as well as in other areas. Instead, both in early and in late bilinguals, no difference in brain correlates was observed during the semantic judgment task. Therefore, this study demonstrates that the age of acquisition is an important variable and affects the neuronal substrate to a greater extent for grammatical than for semantic processing.

The activation pattern related to the proficiency level in L2 has been described in an fMRI study carried out by Chee, Hon, Lee, and Soon (2001). They found that L2 proficiency is negatively associated to the level and number of activated areas in the brain. In particular, activation in the left prefrontal and parietal areas as well as additional activation in the right inferior frontal gyrus were more extended in low proficient bilinguals when compared to highly proficient bilinguals. Similar results of stronger left hemisphere involvement for lower proficiency L2 learners, in terms of synchronized network activation patterns, were also obtained in an EEG study using gamma-band synchronization analyses (Reiterer, Pereda, & Bhattacharya, 2011). This is in line with Green's “convergence hypothesis” (Green, 2003), claiming that as proficiency improves, the neural differences between native and L2 speakers may disappear. Since the L2 is learned in the context of an already acquired language, corresponding neural representation will converge with the one underpinning L1 processing.

Although many studies have focused their attention on hemispheric asymmetries in the bilingual brain, only a few of these have examined the possible influences of cross-linguistic aspects on the neural correlates of L1 and L2 (Chee et al., 1999, 2001; Klein et al., 1999; Pu et al., 2001). These studies compared effects of linguistic similarity on cortical representations between two typologically dissimilar languages: English and Chinese. The obtained results show that there are no significant differences in the location of brain activations with respect to the linguistic distance between L1 and L2.

In recent years however, many bilingualism studies seem to show consensus on a possible effect of similarity between languages and their underlying processing mechanisms. A positive transfer between L1 and L2 has been found when two languages share structural similarities (Tokowicz & MacWhinney, 2005). It has also been shown that word recognition in L2 can be influenced by mother tongue according to a specific L1–L2 combination (Duyck, 2005; van Wijnendaele & Brysbaert, 2002). The reversal effect, i.e. that L2 can influence the native L1 (backward transfer) was observed in late bilinguals living in a native language context (Lagrou, Hartsuiker, & Duyck, 2011; van Hell & Dijkstra, 2002). Differently, an overlapping pattern of L2 processing has been found in a study attempting to explain the role of specific language combinations during word perception in bilinguals with English as L2 and a number of western European native languages (Lemhöfer et al., 2008). Their findings, however, concern word recognition in L2, whereas the focus of our study is to assess hemispheric asymmetry as a function of typological distance between two languages of a bilingual.

In the present study we investigated the lateralization of language in bilinguals with the aim to shed light on the mutual involvement of left and right hemisphere during L1 and L2 perception as a function of their similarity. The study has been carried out in two different groups of bilinguals speaking English as L2: a group of German (L1) natives and a group of Italian (L1) natives. According to linguistics typological considerations, English and German are two similar languages, but English and Italian show more linguistic distance. English and German share several similarities at all levels of linguistic analysis. Therefore, regarding the lexicon, many German words are related with English ones: there are words with identical or similar form, e.g. English *summer* and German *Sommer*, sharing also the same meaning. In addition several morphemes (prefixes and suffixes) have the same or similar form such as the genitive suffix, e.g. English *man's* and German *Mann*(*e*)*s*. All of the three languages of the present study are from the Indo-European language family, but German and English are from the West Germanic branch of the Germanic family and Italian is from the Latin branch of the Italic family. Germanic and Romance languages differ also in their rhythmic structure. German languages are stress-timed, predominantly with one full vowel per word, and have a complex syllable structure. Romance languages are mainly syllable-timed (Ramus, Nespor, & Mehler, 1999), the stress is dynamic rather than tonal, and it is weaker than in Germanic languages (Comrie, 2009).

To assess the hemispheric specialization for language we used the dichotic listening (DL) paradigm, a neuropsychological technique for the study of functional laterality, which allows testing left and right auditory cortices separately (Brancucci & San Martini, 1999, 2003; Brancucci et al., 2004, 2008b; Della Penna et al., 2007; Hugdahl et al., 1999; Tervaniemi & Hugdahl, 2003). It consists in presenting two different auditory stimuli simultaneously to either ear of the subjects. Being a completely noninvasive method, DL has been broadly used in the investigation of hemispherical asymmetries. The hypothesis is that a right ear advantage (REA) indicative of a left hemispheric specialization should be observed in the perception of both German and Italian (L1) and English (L2). However, we expect that L2 asymmetries differ in the two groups, due to the similarity of English with German and dissimilarity with Italian, possibly in the direction of a similar lateralization for similar languages.

2. Materials and methods

2.1. Participants

Thirty German native speakers with English as a second language (22 females, age range = 19–44 years; mean = 26 years) and thirty Italian native speakers with English as a second language (17 females, age range = 20–34 years; mean = 25.6 years) participated in this study. None of them had auditory impairments as measured by auditory functional assessment (Ear Test Johannes Wallroth Berlin, Germany December 2007 http://www.programming.de). Hand preference was assessed using the Edinburgh handedness inventory (Oldfield, 1971); the handedness score ranged from −100 (totally left handed) to +100 (totally right handed). For the German group (mean $\pm$ standard error = 55.96 ± 9.17) 24 subjects scored ≥ 48 (right-hand preference), 3 subjects scored ≥ -28 < 48 (mixed handed), 3 subjects scored ≤ -28 (left-hand preference). For the Italian group (mean $\pm$ standard error = 50.83 ± 8.27) 20 subjects scored ≥ 48 (right-hand preference), 7 subjects scored ≥ -28 < 48 (mixed handed), 3 subjects scored ≤ -28 (left-hand preference).

Subjects were exposed to their first language since birth and they spent most of their lifetime in their home country: the group of German speakers in Germany and

Table 1
Participant characteristics.

		German group	Italian group
N		30	30
Sex	f	22	17
	m	8	13
Age M (SD)		26 (6.54)	25.6 (3.52)
Age of acquisition L2 (AOA) (M, SD)		10.88 (2.32)	9.93 (3.31)
Score TOEFL test		19.41 (2.04)	19.43 (2.18)
Duration of instruction received in L2 (years) (M, SD)		9.67 (3.57)	12.03 (4.32)
Number of hours of training in a week (h) (M, SD)		3.9 (0.9)	4.62 (2.94)
Duration of living in an Anglophone country (months) (M, SD)		9.64 (18.65)	7.10 (16.27)
Number of languages known		2.64 (1.15)	2.14 (1.02)

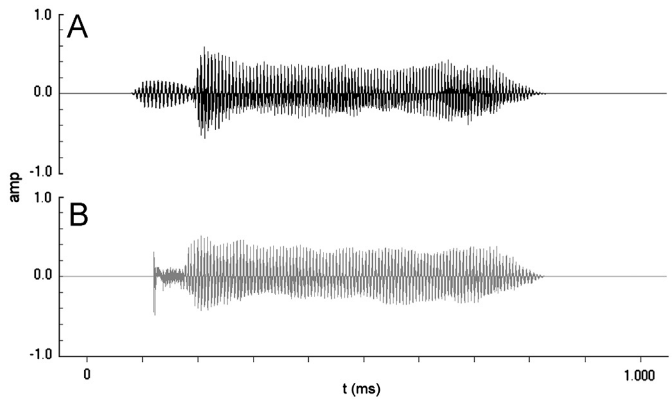

Fig. 1. Waveforms examples of acoustic stimuli used in the test. (A) Waveform of the word *baia* ("bay") presented to the left ear. (B) Waveform of the word *paia* ("pair") presented to the right ear.

the group of Italian speakers in Italy. All subjects learned English at school after the age of six. The mean starting age for bilinguals in the German group was 10.88 (SD: 2.31) and for bilinguals in the Italian group was 9.93 (SD: 3.31). Subjects were living in their home country when they took part in the experiment.

All participants were tested on their English language knowledge, and were evaluated with a survey to assess their English proficiency level, the time they had been studying L2, the hours of formal instruction received, the months spent in an Anglophone country. Furthermore they were evaluated with questions extracted from the TOEFL (Test of English as a Foreign Language) to assess their English grammar knowledge as well as with a home-made vocabulary test. Subjects were recruited on the basis of their proficiency level in L2; only subjects with a good score (from 16 to 20 points) and excellent score (from 21 to 25 points) in the TOEFL test were selected. A summary of demographics and language background of the subjects is given in Table 1.

2.2. Stimuli

The stimulus material consisted of 30 pairs of words for each language (German, Italian and English). The two items of every word pair were made up of the same phonemic structure and stress; they differed only in the first consonant selected between b, d, g, k, d and t. (example of a pair of words in Italian: *baia-paia* ("*bay*"-"*pair*"), see Fig. 1). All words in each language were made up of two syllables where the first could be consonant–vowel (CV) or consonant–vowel–consonant (CVC); we chose to use these syllable structures in order to avoid differences in the phonetic structure of the stimuli between languages. Within each pair, words have been chosen with a similar frequency of use from the German and English CELEX lexical databases (Baayen, Piepenbrock, & Gulikers, 1995) and from the Italian COLFIS lexical frequency database (Bertinetto et al., 2005). Word lists were different in the three languages and there were no translations of the same words. The complete list of stimulus material is illustrated in Table 2.

Words were read aloud by a natural female voice, able to pronounce optimally all the three languages (a trained German university teacher certified for teaching Italian as well as English as foreign languages); they were recorded with a microphone and digitized (16 bit, sampling rate 44,100 Hz) with a computer (*Fujitsu Siemens Computers, Intel* (*R*) *Pentium* (*R*) *processor*). Peak amplitude of the speech stimuli was 80 dBA.

Table 2
List of stimulus words.

English		German		Italian	
Word 1	Word 2	Word 1	Word 2	Word 1	Word 2
Baling	*Paling*	*Bässe*	*Pässe*	*Bacca*	*Pacca*
Bandy	*Dandy*	*Beile*	*Peile*	*Balla*	*Palla*
Batches	*Patches*	*Beine*	*Deine*	*Banda*	*Panda*
Batter	*Patter*	*Biene*	*Diene*	*Basso*	*Passo*
Beachy	*Peachy*	*Birne*	*Dirne*	*Batto*	*Patto*
Begging	*Pegging*	*Bosse*	*Posse*	*Bende*	*Pende*
Bitchy	*Pitchy*	*Bube*	*Tube*	*Bici*	*Dici*
Bony	*Pony*	*Bühne*	*Düne*	*Bollo*	*Pollo*
Bumpy	*Dumpy*	*Bunte*	*Tunte*	*Borgo*	*Porgo*
Butter	*Putter*	*Delle*	*Pelle*	*Cara*	*Gara*
Calorie	*Gallery*	*Deute*	*Beute*	*Cozzo*	*Gozzo*
Classy	*Glassy*	*Dose*	*Pose*	*Desto*	*Pesto*
Cunning	*Gunning*	*Gasse*	*Kasse*	*Dosa*	*Posa*
Daring	*Pairing*	*Gerne*	*Kerne*	*Gallo*	*Callo*
Dizzy	*Tizzy*	*Güsse*	*Küsse*	*Gotta*	*Cotta*
Bearing	*Pairing*	*Taute*	*Baute*	*Paia*	*Baia*
Garret	*Carrot*	*Kehrte*	*Gerte*	*Palco*	*Talco*
Giddy	*Kiddy*	*Paare*	*Bahre*	*Panca*	*Banca*
Goldish	*Coldish*	*Panne*	*Banne*	*Para*	*Bara*
Gutter	*Cutter*	*Paste*	*Taste*	*Pari*	*Bari*
Packing	*Backing*	*Pore*	*Tore*	*Parlo*	*Tarlo*
Patty	*Batty*	*Pulle*	*Bulle*	*Pomo*	*Tomo*
Galling	*Calling*	*Tanne*	*Panne*	*Pelle*	*Belle*
Pity	*Bitty*	*Barde*	*Garde*	*Pere*	*Bere*
Pulley	*Bully*	*Teiche*	*Deiche*	*Pile*	*Bile*
Pushy	*Bushy*	*Tenne*	*Penne*	*Pista*	*Dista*
Tally	*Bally*	*Ticke*	*Dicke*	*Puro*	*Duro*
Tapper	*Dapper*	*Tilde*	*Bilde*	*Tane*	*Pane*
Tatter	*Patter*	*Torte*	*Borte*	*Tasto*	*Pasto*
Tummy	*Dummy*	*Tote*	*Bote*	*Tomba*	*Bomba*

The dichotic stimuli were obtained using the GoldWave (V.5.08, GoldWave Inc.) software. To synchronize the two words exactly and make sure that no undesired alteration was present, the stimuli were re-analyzed visually plus using headphones. The duration of each stimulus was about 650 ms.

2.3. Procedure

Subjects were presented with two dichotic tests, one in L1 and the other in L2. The two tests were performed separately in two consecutive sessions and the order of tests was counterbalanced across subjects. Each test was composed of 120 trials. Order of stimulus presentation was randomized. Each trial consisted in the following sequence: a dichotic pair of words, followed by the visually presented response screen. The interval between the onsets of the dichotic pair and the response screen was of 1300 ms.

The response screen was composed of two stimulus words (the same as those composing the dichotic pair), presented on the computer monitor, one on each side of the display; they were written inside two squares separated by a 4 cm space. The task for the subjects was to indicate which word they had heard better by clicking with the mouse on the corresponding word on the display using the right hand.

The options remained on the screen until the response was given by the subject. The trials were separated by a 2000 ms inter-trial interval. Each experimental session lasted approximately 10 min. Type and latency of response were automatically stored for subsequent analyses.

Stimuli were presented using a computer and the experimental procedure was completely automated using a software written in E-prime (Psychology Software Tools, Inc.). Subjects were tested in a quiet room, they sat comfortably in front of the computer monitor (approximately 70 cm from subject's head) and wore a pair of headphones (Philips SHP 1900). They were instructed to pay attention to both ears and not to shift their gaze laterally during the experiment. All instructions were given in written form on the computer display. Before performing the test, each subject was familiarized with 4 practice trials. In the experimental phase, the initial position of the headphone was counterbalanced across subjects. After 60 trials (middle of test), subjects turned the orientation of the headphone. To control for possible interaction effects due to acoustic and visual lateralization of the words, the side of presentation of dichotic pairs and response screen was completely counterbalanced; a word could be heard in the right or left ear, and in the corresponding visual response choice one word was presented on the left side and the other word on the right side of the screen.

Of note, all subjects were tested in their home country, Italians in the University of Chieti and Pescara, Germans in the University of Tübingen.

3. Results

3.1. Statistical analysis

Statistical effects were evaluated by repeated measures analysis of variance (ANOVA) at a significance level of $p=0.05$, using the Statistica 7 software. Dependent variables were the number of responses, the number of times the subjects choose the words presented on one side and the associated reaction time. Of note, the choice was always made between two words presented visually, one matching the word presented at the left ear, and the other matching the word presented at the right ear. Responses given 4 s after the on-set of the response screen were excluded.

For the statistically significant results we calculated the effect size (Cohen's d); that is an index of the magnitude of the difference between groups. Effect sizes of about 0.2, 0.5, and 0.8 are categorized, respectively, as small, moderate, and large (Cohen, 1977).

Preliminary statistical analyses showed that sex and handedness of the participants did not influence statistical results. The headphone position at the beginning of the test (upright or reversed) and the order of test administration (whether participants first received the L1 or the L2 test) showed no significant interactions with laterality scores. These variables were therefore not included in the subsequent analyses.

3.2. Main analyses

A 2 × 2 × 2 analysis of variance, with Group (German, Italian) as the between-subjects factor and Ear (right ear, left ear) and Language (L1, L2) as within-subjects factors, was performed on the data (number of responses and reaction time). Mean results are illustrated in Figs. 2–4.

Regarding number of responses, results showed a significant main effect of Ear of input ($F_{1,58}=84.3$, $p<.001$), indicating a REA effect. A subsequent analysis of the simple main effects showed that the REA was significant in both the German ($p<.001$) and the Italian group ($p<.001$), due to a right-ear advantage. The three-way interaction of Group, Ear and Language ($F_{1,58}=6.56$, $p=.013$) was significant due to a stronger REA for L2 compared to L1 in the German compared to the Italian group. Duncan's post hoc comparisons between German and Italian group in L2 perception were significant for both left ear ($p<.001$; Italian > German) and right ear ($p=.029$; German > Italian). Duncan's post hoc comparisons between L1 and L2 were significant in the German group for both the left ear ($p=.013$; L1 > L2) and right ear ($p=.02$; L1 < L2). For the Italian group post hoc comparisons were not significant. The effect size (Cohen's d, Cohen, 1977) of the ear asymmetry for accuracy was ‘large’ in both groups (German group: $d=1.60$, Italian group: $d=1.35$). The effect size calculated for ear asymmetry for L2 perception between German and Italian group was between ‘large’ and ‘medium’ in the left ear ($d=0.52$) and between ‘small’ and ‘medium’ in the right ear ($d=0.28$). The effect size of ear asymmetry for the German group between L1 and L2 perception was between ‘large’ and ‘medium’ in both ears (left ear: $d=0.54$, right ear: $d=0.51$).

Laterality index (LI) was calculated according to the formula $LI=(R-L)/(R+L)\times 100$, where R is the number of responses for the right ear and L is the number of responses for the left ear (Table 3).

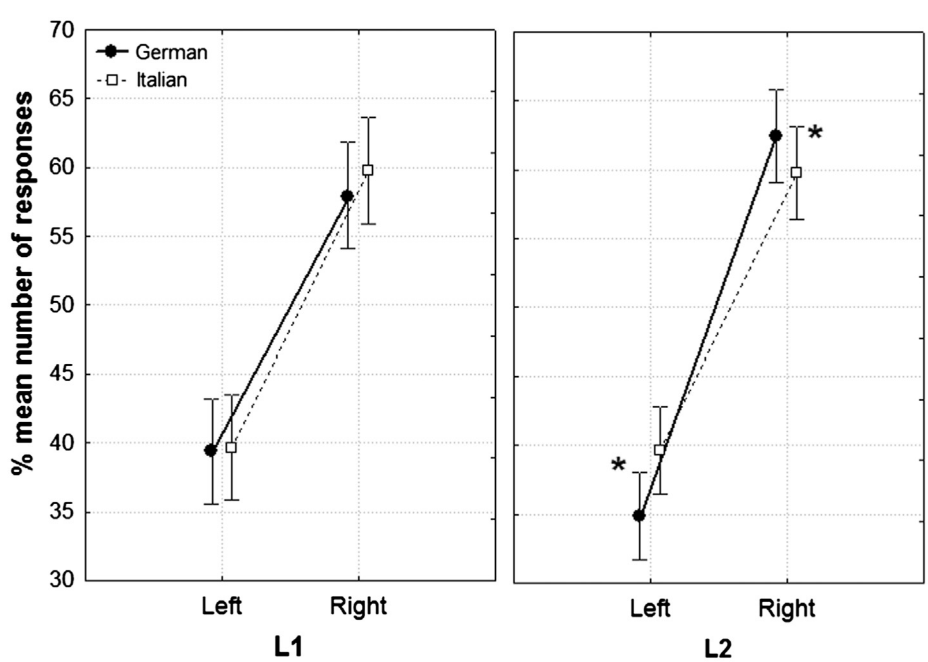

Fig. 2. Mean values (±0.95 confidence interval) of responses to words presented at the left and right ear for the German and Italian group (L2 is English for both groups).

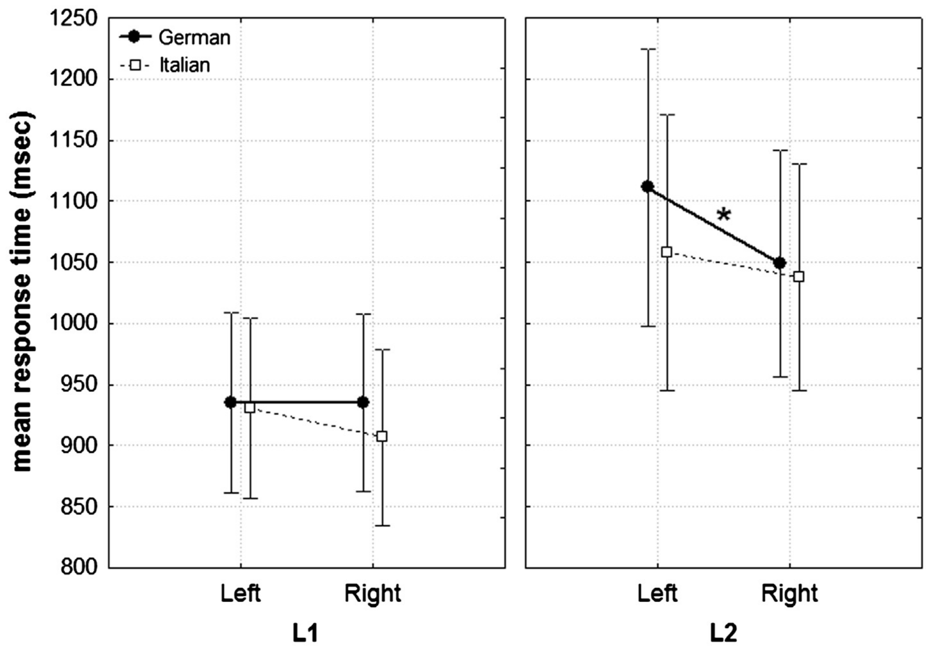

Fig. 3. Mean response time in milliseconds (± 0.95 confidence interval) to words presented to the left or right ear for the German and Italian group (L2 is English for both groups).

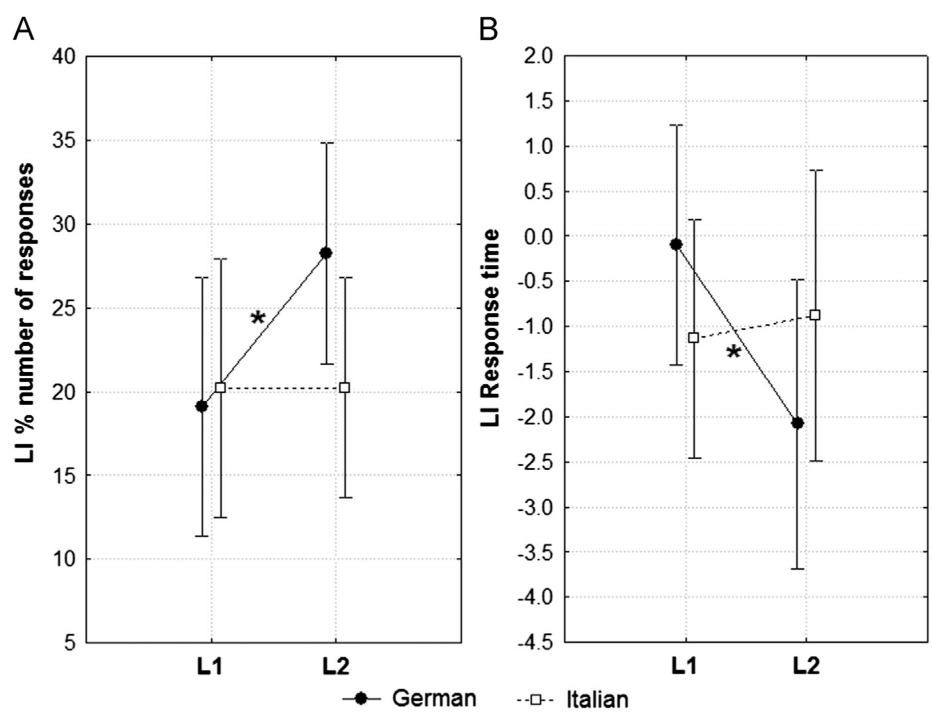

Fig. 4. (A) Laterality index for % number of responses. (B) Laterality index for response time.

The two-way interaction between Group and Language ($F_{1,58}=6.70$, $p=.012$) was significant. Post hoc Duncan's test showed that comparison between L1 and L2 in the German group was significant ($p<.001$), indicating that the advantage of the right ear during L2 perception was stronger than during L1 perception.

Regarding reaction time, there was a significant main effect of Language ($F(1,58)=30.82$, $p<.001$) in both groups, due to shorter times of response for L1 compared with L2. Duncan's post hoc comparisons between L1 and L2 perception in the Italian group were significant for both left ear ($p<.001$) and right ear ($p<.001$) indicating that L1 was faster than L2; also in the German group post hoc comparisons were significant for both left ($p<.001$) and right ear ($p<.001$) indicating that L1 was faster than L2.

The three-way interaction between Group, Ear and Language was significant ($F_{1,58}=4.46$, $p=.039$). Post-hoc comparisons were significant in the German group in L2 perception between left and right ear ($p<.001$); indicating an advantage of the right ear. In the Italian group post hoc comparisons were not significant.

Laterality indices (LI) calculated according to the formula $LI=(R-L)/(R+L)\times 100$, where R is the reaction time for the right ear and L is the reaction time for the left ear (Table 3) shows that the

Table 3
Descriptive values and laterality index (mean ± standard error) of mean number of responses and reaction times in L1 and L2 tests on the left and right ear.

		L1			L2		
		Ear left	Ear right	LI	Ear left	Ear right	LI
Accuracy							
Group	German	39.39	57.94	19.07 ± 2.87	34.86	62.44	28.25 ± 3.31
	Italian	39.64	59.78	20.22 ± 4.75	39.61	59.78	20.23 ± 3.37
Reaction time							
Group	German	935.45	935.27	−0.1 ± 0.66	1111.07	1049.17	−2.08 ± 0.97
	Italian	931.07	906.77	−1.14 ± 0.69	1057.77	1038.25	−0.88 ± 0.63

two-way interaction between Group and Language was not significant. Post hoc Duncan's test showed that comparison between L1 and L2 in the German group was significant ($p=.05$) confirming the right ear advantage during L2 perception. The effect size of the Language for reaction time between L1 and L2 in the Italian group was between 'medium' and 'small' in the left ear ($d=0.48$) and between 'large and 'medium' in the right ear ($d=0.52$). In the German group it was between 'large and 'medium' in both ears (left ear: $d=0.62$, right ear: $d=0.52$). Finally, the effect size for ear asymmetry for L2 perception in the German group was between 'medium' and 'small' ($d=0.22$). A summary of descriptive values and laterality index of the subjects is given in Table 3.

4. Discussion

The present results showed an overall REA suggesting a left hemispheric specialization in the perception of words in both L1 and L2 in bilingual healthy subjects. This results is in general agreement with the literature of the classical right-ear effect for speech perception (Della Penna et al., 2007; Gordon & Zatorre, 1981; Hugdahl, 2002; Kimura, 1967; Ip & Hoosain, 1993). The aim of the study was to investigate whether this REA could be modulated in bilinguals on the basis of the similarity between L1 and L2, in a first attempt (to our knowledge) to investigate the influence of linguistic similarity between L1 and L2 specifically on hemispheric asymmetry.

In addition, while several studies have focused on the comparison between very different languages, we used two mother tongues, German and Italian, and one common L2, English, all belonging to the same language family, the Indo European group. We found that when the two languages arise from the same root (i.e. German and English Anglo-Saxon languages) the REA for L2 (English) is stronger than the REA for L1 (German). Conversely, when the two languages arise from different roots (Italian, a Latin language, and English) the REA for L2 (English) does not differ from the REA for L1 (Italian).

Although actually, in some studies males have been described to be more lateralized for language than females (Lust et al., 2010; Voyer, 1996) regarding our results this bias should have been negligible. In fact, the German group (the one with more females) scored as more lateralized than the Italian group for L2.

We can rule out that these different asymmetries are associated to factors such as age of acquisition and proficiency level in L2. Indeed both groups of subjects started to learn English late in life and at the same age of around 10 years. Moreover, subjects of the two groups had the same proficiency level in L2 and they all lived in their home country when they took part in the experiment. Excluding that differences found in the lateralization pattern are due to manner of second language acquisition, is arguable that they might be explained by language-specific factors. It has been suggested that features of particular languages might produce different pattern of laterality in bilinguals (Evans, Workman, Mayer, & Crowley, 2002; Workman, Brookman, Mayer, Rees, & Belin, 2000).

We can hypothesize that different lateralization patterns could be found comparing languages from two different roots, such as a non-Indo-European L1 with an Indo-European L2. The processing of a tonal language like Chinese, for instance, might be associated with a RH bias (Valaki et al., 2004; Green, Crinion, & Price, 2007), differently from the processing of an Indo-European language, in which a LH involvement is expected.

In the present study results provide information concerning the neuropsychological substrates of L1 and L2 processing in bilinguals and show that when L2 is different from L1 the overlap between the two languages is low, whereas when L1 and L2 come from different roots the overlap is strong. This suggests that a strong similarity between two languages produces interferences within the multifaceted neural mechanisms implemented in the speech areas devoted to their processing, which results in an exile of L2 to different, possibly in part contralateral, brain areas. Conversely, the same neural speech mechanisms would be less affected by interference when the two languages (L1 and L2) are substantially different.

It should be noted that the left hemisphere specialization reported here about L1 and L2 perception is consistent with previous results in the literature. While left hemisphere specialization for speech in right handed individuals is a well established issue, the hemispheric lateralization in bilinguals is still an open question. Early language learning experiences seem to affect brain organization pattern; in fact late bilinguals resemble monolinguals in their left hemisphere language specialization, both exposed to only one language before the age of six. Conversely, early bilinguals who learn more than one language during the first 6 years show more bilateral participation (Hull & Vaid, 2006). Moreover the left hemisphere involvement seems to increase with L2 proficiency, and non proficient bilinguals are more lateralized towards the right hemisphere compared to the left hemisphere asymmetry of high proficient bilinguals.

Our results confirm in part the greater LH lateralization observed in high proficiency bilinguals (Hull & Vaid, 2006). The increased left hemisphere involvement found in the German group during L2 processing could be due to a typological similarity between German and English. Our results, supported by post-hoc comparisons, show that lateralization increases only in the German group during L2 processing. This LH bias in the German group is hypothesized to result from a facilitation between the language networks underlying two similar tongues such as German and English. Therefore this could result in a greater involvement of the hemisphere specialized for language functions during the L2 processing in the German group.

Recently, a large number of neuroimaging studies have tried to explore the localization of multiple languages. Functional neuroimaging evidence of linguistic similarity effects on second language cortical processing arise from one fMRI study of Jeong et al.

(2007a) on Korean trilinguals. They found similar activation patterns between two similar languages (Korean and Japanese) and a stronger activation during listening to English. The relation between the activation pattern and linguistic differences has been confirmed comparing two native speaker groups (Chinese and Korean) with the same second languages (English and Japanese). Stronger activation during English phrase comprehension was found in the Korean group than in the Chinese group (Jeong et al., 2007b). These results show that linguistic similarity between L1 and L2 can affect cortical representation of the language system but are different from ours in showing a similar cortical activation pattern when L2 is typologically more similar to L1, than when L2 is more distant from L1. It should be however noted that the observed differences can be due to the longer exposure time to Japanese language and to the greater effort required in the processing of English sentences because of the wide different syntactic structure compared to Korean phrases. This could explain the increased cortical area involvement found during English comprehension requiring additional cognitive resources.

The emerging view from repeated studies reported in the specific literature is that the main difference between L1 and L2 is a stronger neural activation underlying L2 processing with more regions activated (Indefrey, 2006). A possible explanation for a more extensive recruitment of areas could be the stronger cognitive effort required for languages acquired later and with less proficiency (Briellmann et al., 2004; Vingerhoets et al., 2003). In fact this happens especially for bilinguals with late L2 onset, with low L2 proficiency, or low L2 exposure (Obler, 1981). Specifically late bilinguals appear to require the activation of additional left hemisphere regions for the L2 processing (Kim et al. 1994; Klein et al., 1994; Reiterer et al., 2011), with an involvement of a more variable neural network. Proficiency level in L2 is critical in the organization of the bilingual brain (Kotz, 2009; Reiterer, Pereda, & Bhattacharya, 2009). Several works reported a highly variable network during L2 processing, with a more widespread activation into the right hemisphere, particularly when participants are less proficient in L2 (Dehaene et al., 1997; Perani et al., 1998; Reiterer et al., 2009). It is an ongoing debate to pin down the most crucial factors in bilingual brain organization, proficiency level and/or age of onset being only some of them. Additionally, individual differences in L2 learning further complicate this issue (Reiterer, 2010). Even individual differences in hemispheric specialization should be taken more into consideration in future research on this issue.

5. Conclusion

In this study we found differential lateralization patterns in bilinguals with English as L2, but different native languages (stronger leftward lateralization, if L1 and L2 are typologically similar)—irrespective of proficiency level and age of onset of language learning. We conclude that linguistic distance/similarity is a further important factor which can affect resource allocation and resource competition in the brains of bilinguals.

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