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Evidence for reduced hemispheric asymmetries in non-verbal functions in bilinguals

Markus Hausmann[a,*], Gökce Durmusoglu[b], Yanki Yazgan[b], Onur Güntürkün[a]

[a]*Institute of Cognitive Neuroscience, Department of Biopsychology, Faculty of Psychology, Ruhr-University Bochum, GAFO 05/620, D-44780 Bochum, Germany*

[b]*Department of Child and Adolescent Psychiatry, Marmara University Faculty of Medicine, Istanbul, Turkey*

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Abstract

Hemispheric asymmetries in verbal and non-verbal visual half-field tasks were studied in highly proficient Turkish–German bilinguals. Besides a typical left-hemisphere advantage in word matching for both languages, a reduced right-hemisphere advantage in face discrimination in bilinguals was found as indicted by response times measures. In contrast, monolingual controls showed typical hemispheric asymmetries in both tasks. The results suggest that language experience affects the cerebral organization of non-language abilities which are known to show a right hemisphere advantage. It is conceivable that the acquisition of a second language leads to substantial modifications in various cortical areas, and thus affects cerebral organisation of other functional domains.

Keywords: Lateralization; Language; Language proficiency; Language acquisition; Word matching; Face discrimination; Turkish–German bilinguals

1. Introduction

The two cerebral hemispheres of the human brain are functionally specialized with the left hemisphere (LH) predominantly mediating different language skills. The basis of this lateralization has been proposed to result from the differential localization of linguistic, motor, or symbolic properties of vocal and non-vocal language (Corina, Vaid, & Bellugi,

* Corresponding author. Tel.: +49-234-32-24323; fax: +49-234-32-14377.
E-mail address: markus.hausmann@ruhr-uni-bochum.de (M. Hausmann).

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1992). Besides this pattern of left hemisphere superiority for verbal functions, a right hemisphere superiority is typically found for specific non-verbal functions, particularly for visuospatial abilities and configuration based face processing (Hausmann & Güntürkün, 1999, 2000).

Studies investigating hemispheric asymmetries of language functions have dealt almost exclusively with monolingual subjects. To the extent that experiential factors influence lateralization, bilingualism, representing a distinctive form of language experience, may have an important influence on hemispheric specialization (Vaid & Lambert, 1979). This potential influence might not be restricted to the lateralization of verbal functions, but also of functions which are predominantly organized in the right hemisphere. However, the majority of studies using bilinguals within the lateralization paradigm have concentrated only on linguistic tasks (Eviatar, 1997).

The results of different clinical and experimental studies suggest that competence in more than one language may influence brain functioning such that it differs from the typical speakers of a single language (Vaid, 1983). One of the most prominent positions suggests a greater right hemisphere involvement in bilingual language functioning (Albert & Obler, 1978). Others supposed that this observation of a greater right-hemisphere involvement in bilingual language functioning is more a function of the proficiency in language abilities or the age of language acquisition (for review: Vaid, 2002).

However, the suggestion that language functions in bilinguals might be less strongly lateralized has not received unanimous support. Clinical studies showed equal deficits in all languages, parallel recovery of language functions, and same incidence of crossed aphasia in bilinguals and monolinguals (Fabbro, 2001; Karanth & Rangamani, 1988; Paradis, 2000), which suggests a common or significant overlap of neuronal networks for different languages. These results support the notion that the functional cerebral asymmetries (FCA) of bilinguals do not differ from the typical left-hemispheric dominance for language of the monolingual brain and Paradis even stated that "there is not a shred of clinical evidence in support of less asymmetry of language representation in bilinguals for either or for both of their languages" (Paradis, 1990, p. 578).

The assumption of common neuronal networks is also supported by the majority of imaging studies (Chee, Tan, & Thiel, 1999; Hasegawa, Carpenter, & Just, 2002; Hernandez, Martinez, & Kohnert, 2000; Illes et al., 1999; Klein, Milner, Zatorre, Meyer, & Evans, 1995). For instance, Chee et al. (1999) investigated subjects who were bilingual in English and Chinese (Mandarin) with functional imaging (fMRI) and found that any asymmetry of brain activation during word generation was similar for both languages. Although there were differences in the magnitude of activation between the pair of languages, no subject showed significant differences in peak location or hemispheric asymmetry of brain activation. Similar pattern of overlapping activations were even found in early and late bilinguals (Chee et al., 1999; Klein et al., 1995).

In contrast, Dahaene et al. (1997) found differences in the cortical representation of first and second language. The conflicting finding of a reduced left-lateralization for the second language in a story listening task in Dahaene et al.'s study, might be due to the fact that only moderate fluent bilinguals were investigated. Proficiency cleary affects the cortical representation and processing of the second language and seems to be more important than age of acquisition. Less proficient bilinguals showed different activation patterns when listening to first and second language whereas highly proficient late learners showed no differences between languages (Perani et al., 1998).

A recent study (Chee et al., 2003) confirmed that overlapping brain areas are activated when fluent bilinguals process words or sentences in different languages. However, this study showed not only common but also segregated neural networks for different languages. This is supported by cortical stimulation studies which showed that in some cases different languages can be sustained by language and task-specific cortical areas (Ojemann & Whitaker, 1978; Roux & Tremoulet, 1996).

Although differences in cortical representation between first and second language might exist on a finer level (Chee et al., 2003), Paradis (1990) concludes from the literature of the last three decades that language abilities, whether mono- or multilingual, are organized in a similar way in the left hemisphere of humans and that no qualitative differences between the bilingual and the unilingual brain exist (Paradis, 2000). If this is true, can we generalize this statement to non-verbal functions that typically show a right hemisphere advantage?

Eviatar hypothesized that "given resource limitations on cognitive processes, it may be that the expertise and sophistication of the language functions of multilinguals has an effect on the manner in which non-language tasks are organized or accessed in the cortex" (Eviatar, 1997, p.159). Since speech is a multifaceted process that requires multiple subsystems which are distributed not only over left hemisphere, the switch from a monolingual to a bilingual system might create impacts on various cognitive processes outside the language domain. Unfortunately, there are only few studies investigating hemispheric asymmetries of other than verbal functions in bilingual subjects. In a study of Sewell and Panou, (1983), visual field asymmetries for a left-hemispheric word-recognition task and a right-hemispheric dot localization were examined in monolinguals and English–German as well as English†French bilingual subjects. In the word-recognition task, 25 four-letter concrete nouns for each language were presented tachistoscopically, with stimuli occurring once in each visual field. The stimuli in the right-hemispheric dot location task were single dots which could occupy 1 of 20 positions, enclosed by a drawn rectangular frame positioned in the left or right visual field. The position of each dot was numbered with the numbers being in random order, and subjects were required to indicate the position of the dot displayed by giving the number associated with the position (Kimura, 1969). In Sewell and Panou's study, the bilingual subjects showed a left-hemisphere advantage for the processing of concrete nouns irrespective of language of testing, but an absence of asymmetry in the non-verbal dot-location task. Monolingual subjects displayed the usual left-hemisphere advantage for verbal material and a consistent right-hemisphere advantage in the spatial task. Additionally, although all groups displayed a consistent left-hemisphere advantage in the verbal task, bilingual subjects showed a reduced lateralization for their second language compared with their native language. The authors could replicate their findings in another study (Panou & Sewell, 1984) investigating congenitally deaf subjects, who were exposed to half-field-stimulated presentation of concrete English nouns (word-recognition task), British Sign Language, manual letters, and the non-verbal dot-location task. Again they found a right visual-field advantage for the verbal tasks, for English words and signs, whereas no field differences appeared for the non-verbal task. Unfortunately, these studies included no information on acquisition and proficiency in both languages. Although these data suggest that bilingualism may affect the access or availability of right-hemisphere abilities, this is not supported by a study that investigates the influence of language experience and the performance in right-hemisphere tasks (Eviatar, 1997). This study explored the effects of multilingualism and reading habits on right-hemisphere abilities in native Hebrew speakers and Arabic–Hebrew bilinguals. In this study the bar-graph task and an emotional face-perception task was used, which usually show a right-hemisphere advantage (Boles, 1986; Levy, Heller, Banich, & Burton, 1983; Levine & Levy, 1986). The bar-graph task is a numerical odd/even judgement task which used a rectangular bar arranged vertically, with length of the bar denoting to a numerical value of 1–8 (whole numbers). Subjects had to decide per keypress if the represented number was odd or even (Boles, 1986). The emotional face-perception task involved deciding which member of a pair of face chimeras presented in free vision looks happier, the one with the smile to the left or its mirror image with the smile to the right (Levy et al., 1983; Levine & Levy, 1986). The results of Eviatar's study did not support the hypothesis that multilingualism can affect the manner in which these non-language tasks are subserved by the right hemisphere. However, this study did not measure hemispheric asymmetry in any language-related task. Thus, the hypothesis that language experience may affect the lateralization status of right- rather than left-hemisphere tasks was not tested directly. It remained unclear whether bilinguals and monolinguals of this study differed in hemispheric asymmetry of language abilities and which function was more affected.

Due to this fact, we intended to investigate highly proficient Turkish–German bilingual subjects in a verbal task, which typically lead to a strong left-hemisphere advantage, as well as in a face-discrimination task, which typically showed a very strong right-hemisphere advantage (Hausmann & Güntürkün, 1999, 2000; Hausmann, Güntürkün, & Corballis, 2003). Moreover, we intended to analyse the age and setting of language acquisition as well as the proficiency for both languages. Asymmetry data were compared to German monolinguals.

2. Methods

2.1. Participants

Seventy-seven subjects, 40 females and 37 males, participated in this experiment. Thirty-two of them were Turkish–German bilinguals (15 females, 17 males), whereas the remaining 45 subjects were German monolinguals (25 females, 20 males). The mean ages were 27.06 (SD = 5.15) years for the bilingual group and 26.62 (SD = 6.90) years for the monolingual group. The handedness of all subjects was determined with the Edinburgh-Inventory (Oldfield, 1971). The asymmetry index (LQ) provided by this test is calculated as $((R - L)/(R + L)) \times 100$, resulting in values between -100 and $+100$. Positive values indicate dextrality, while sinistrality results in negative values. The mean handedness score was 88.15 (SD = 15.09) for bilinguals and 84.09 (SD = 18.95) for monolinguals. Participants who had used any medication affecting the central nervous system during the last 6 months were excluded. All subjects had normal or corrected to normal visual acuity and were naïve to the study's hypothesis. They were recruited by announcements and were paid for their participation.

2.2. Tasks and procedure

A pool of 105 German nouns was used for the German version and 105 Turkish nouns were used for the Turkish version of the word-matching task.[1] For both languages the nouns consisted of at least four letters up to a maximum of seven. The stimuli were selected for a high degree of abstraction to maximize the left-hemisphere advantage. German and Turkish stimuli were collected from a study analysing the abstractness of 800 German nouns (Baschek, Bredenkamp, Oehrle, & Wippich, 1977). Translation equivalents of the German nouns were used for the Turkish stimuli. The abstractness of the Turkish nouns were assumed to be comparable to the German nouns. Each trial started by presentation of a fixation cross for 2 s. Next, a noun appeared in the centre of the monitor for 185 ms. Then, a fixation cross was presented for 2 s again, followed by a noun for 185 ms pseudorandomized in the left visual field (LVF) or right visual field (RVF). A subsequent question-mark instructed the subject to decide by key press if both nouns were the same or different. Each abstract noun was used only within one trial. In a matching trial, the same abstract noun was presented twice, once centrally and once laterally in the left or right visual field. In the mismatching trials, nouns were identical with regard to the initial letter and to the number of letters (e.g. Turkish: Gelecek [Future]-Gelenek [Tradition]; German: Chance [Chance]-Charme [Charm]). Each language condition (German and Turkish) consisted 60 trials. In previous studies (Hausmann & Güntürkün, 1999, 2000; Hausmann et al., 2003), results of the German version of the task consistently showed a higher accuracy for words presented in the RVF, corresponding to the left hemisphere.

Photographs for the face-recognition task were taken from a US college album from the 1950 s. The students on these pictures were all male, clean-shaven, short haired, without glasses, and in their early 20 s. To avoid further non-facial characteristics, all photographs were framed with an ovoid overlay that covered the background and the clothes, with the exception of the collar. Thirty-five Normal and 35 altered 'monster' faces were used as stimuli. For the latter stimuli some facial characteristics were translocated. For example, the position of one eye and the mouth were swapped, or everything was deleted except the nose, etc. All faces were shown in the same upright orientation and had unemotional, neutral expressions (Hausmann & Güntürkün, 1999). After presentation of a fixation cross for 2 s, the stimuli appeared lateralized pseudorandomly either in the left or the right visual half-field, while an empty frame was presented in the other VHF. The participants were instructed to indicate by key press whether the faces they saw were unchanged, 'normal' faces of male college students or altered, 'monster' faces. In previous studies (Hausmann & Güntürkün, 1999, 2000; Hausmann et al., 2003), this task showed a very strong advantage in accuracy and response times (RT) for the LVF, corresponding to the right hemisphere.

[1] The German and Turkish word stimuli are available on request.

The visual half-field (VHF) procedure was identical to previous studies (Hausmann & Güntürkün, 1999, 2000; Hausmann et al., 2003). The experiment started by placing the head of a subject in a chin rest at a distance of 68 cm from a monitor. All subjects were instructed to keep their head and body still during the whole test and to fixate on a cross in the center of the screen. Thus, we ensured that lateralized stimulus presentation was more than 2° visual angle to the left or to the right of the fixation cross. We used an exposure time of 185 ms for all stimuli due to the more difficult face discrimination task. All stimuli were presented within a frame of 4.8 cm wide and 4.5 cm high, 4.0 and 3.8° visual angle, respectively. All tasks included 70 trials. The first 10 practice-trials were eliminated. After 40 trials the responding hand was changed in a balanced order. Each stimulus (abstract noun or face) was only used within one trial. The order of the stimuli as well as the order of the verbal, non-verbal condition was randomised. No effect of order was present. Frequency of correct answers and median response times for both VHFs were used as dependent variables.

Language use histories, comfort levels for using each of their languages, and self-rated proficiency for speaking, reading, writing and understanding Turkish and German were collected by questionnaires. These questionnaires were adapted from Weber-Fox and Neville (1996). Moreover, we directly measured proficiency in specific language functions by different tests, which are described below.

The bilingual questionnaire included questions about the place of birth of the participants and their parents, their time of arrival in Germany, how long they lived in Germany, which language they spoke first, at what age they started speaking Turkish/German, in which setting they learned Turkish/German, and in which language they feel more confident. Additionally, we asked all participants about the relative frequency they used Turkish/German in different settings (at school, at home, at other places, at university, at work) within different life periods (in infancy, in childhood, as an adolescent, as an adult). Language use was measured by this questionnaire using a 7-level scale (1 = only Turkish, 2 = generally Turkish, rarely German, 3 = often Turkish with at least a quarter of time German, 4 = same frequency, 5 = often German with at least a quarter of time Turkish, 6 = generally German, rarely Turkish, 7 = only German). Self-rated proficiency in understanding, reading, speaking, and writing was collected for each language by this questionnaire using a 4-level scale (1 = perfect, 2 = good, 3 = sufficient, 4 = hardly).

Three language tasks served as direct measures of proficiency in Turkish/German bilinguals. *Proficiency in reading* (developed by the authors): all participants had to read a story as fast and as correct as possible. The story was taken from a textbook that includes a Turkish as well as a German version of the text. The number of words during one minute was recorded. *Word fluency* is a subtest of the Leistungsprüfsystem [Performance Test System, Horn, 1983]: all bilingual subjects had to write as many words as possible on a sheet of paper, beginning with ‘K’, ‘A’, ‘S’ in Turkish and ‘L’, ‘E’, ‘R’ in German. For each letter the subjects had one minute. For the analysis we used the total number of words for each language. *Building sentences* is a subtest of the Verbaler-Kreativitäts-Test [Verbal-Creativity-Test, Schoppe, 1975]: Ten items were presented and each of them contained between four and nine words. Subjects had to use all words within one item to build sentences. To solve the task subjects had to choose prepositions, tense, etc. For each logical and correct sentence we assigned one point. That resulted in a maximum score of ten points in this task. (Example: scientist, good, only, statistics, write, neurolinguistics. Possible solution: A scientist should be not only good in statistics when he intends to write a paper for Journal of Neurolinguistics). The Turkish versions of all tasks were adopted from the German versions.

2.3. Designs and statistics

Wilcoxon test (*Z*-score) was used in self-rated acquisition and proficiency data due to significant deviations from normal distribution (Kolmogorov–Smirnov-Test for one-sample). Other proficiency data were analysed using paired *t*-tests.

Firstly, FCA in a German and a Turkish version of the word matching task and a face discrimination task was analysed for Turkish–German bilinguals only. The data of both word matching tasks were analysed by a $2 \times 2 \times 2 \times 2$ ANOVA with repeated measures with visual half-field (LVF − RVF) as within-subject and language (Turkish–German), gender (males–females), and acquisition (early [0–5 years, $N = 17$] − late [6–32 years, $N = 15$]) as between-subjects factors. Asymmetry data of the face discrimination task were analysed by a $2 \times 2 \times 2$ ANOVA with repeated measures with again visual half field (LVF–RVF) as within-subject and gender (males–females), and acquisition (early–late) as between-subjects factors.

Secondly, we compared the FCA in the German word matching task and the face discrimination task of bilinguals with monolingual controls. To investigate potential differences in FCA of each task between bilinguals and monolinguals we analysed the data using a $2 \times 2 \times 2$ ANOVA with repeated measures. We included visual half-field (LVF − RVF) as within-subject and group (bilinguals–monolinguals) and gender (male–female) as between subject factors.

Thirdly, we analysed the relationships between FCAs, acquisition and proficiency data in bilinguals. To analyse these relationships using Pearson's product moment correlation statistics, we computed an asymmetry index (AI) for each task and each dependent variable (response times, accuracy) using the formula ((RVF − LVF)/(RVF + LVF)). This index ranges between −1 and +1 and shows the strength of a task-related asymmetry independent from the overall performance level. For accuracy, positive values indicate an advantage for the RVF, corresponding to the left hemisphere, and negative values indicate a LVFA, corresponding to the right hemisphere. For the response times, positive values are a result of slower response times for the RVF and thus indicate an advantage for the LVF, and vice versa for the negative values. AIs were correlated with direct measures of proficiency, acquisition age, and among themselves. Due to the large number of inferential statistical tests we used a significance level of 1%.

Alpha adjustments of post hoc tests were realized using the sequentially rejective multiple test procedure (Holm, 1979).

Table 1
Birth place of bilingual participants and their parents

Birth place	In Germany (%)	In Turkey (%)
Bilinguals	46.9	53.1
Mothers	–	100
Fathers	–	100

3. Results

3.1. Language proficiency and acquisition data

Nearly half of the bilingual participants were born in Germany, whereas their parents were all born in Turkey (Table 1). The time they were living in Germany and the language use within different life periods as well as different settings are shown in Table 2. Although the time they were living in Germany and the language use of German and Turkish strongly differed among all bilinguals, most of them (62.5%) stated that they feel confident in both languages to an equal extent (Table 3). However, bilingual subjects showed significant differences in self-rated data proficiency in different language functions (Table 4). Although they stated to be more proficient in German for speaking, reading, writing, and understanding, direct measures of proficiency yielded a better performance in German for reading only ($T(30) = -11.06, p < 0.0001$). However, it should be noted that acquisition of Turkish occurred significantly earlier than that of German (Wilcoxon, $Z = -4.53, N = 32, p < 0.0001$). Means, standard deviations, and inferential statistics of acquisition and proficiency data in Turkish–German bilinguals are shown in Table 4.

Table 2
Language use during different life periods and settings

Language use		Mean (SD)	range
In infancy		2.03 (1.23)	1–5
In childhood	At school	4.13 (1.98)	1–7
	At home	1.75 (1.19)	1–6
	At other places	3.59 (1.90)	1–7
As adolescent	At school	5.00 (1.70)	1–7
	At home	2.28 (1.25)	1–5
	At other places	4.31 (1.51)	1–7
As adult	At work/university	5.09 (1.30)	2–7
	At home	3.34 (1.79)	1–7
	At other places	4.44 (1.27)	2–7
Years in Germany		21.94 (4.06)	7–28

Language use was measured by questionnaire using a 7-level scale (1 = only Turkish, 2 = generally Turkish, rarely German, 3 = often Turkish with at least a quarter of time German, 4 = same frequency, 5 = often German with at least a quarter of time Turkish, 6 = generally German, rarely Turkish, 7 = only German).

Table 3
Number of bilinguals who feel more confident in one language or in both to equal extent

	German (%)	Equal (%)	Turkish (%)
Language in which bilinguals feel more confident	21.9	62.5	15.6

3.2. Hemispheric asymmetry

Descriptive statistics for accuracy and response time are shown in Table 5.

3.2.1. FCA in bilinguals (only)

3.2.1.1. Word-matching tasks. Analysis of the accuracy data revealed a significant main effect for VHF ($F(1, 27) = 5.84, p < 0.02$), indicating a strong right visual field advantage. No further main effect or interaction reached significance (all Fs$(1, 27) < 0.84$, ns). Moreover, the analyses of the response times did not show any significant result (all Fs $(1, 27) < 2.56$, ns).

Table 4
Differences in acquisition and proficiency between both languages in German–Turkish bilinguals

	Language	Mean (SD)	Statistics and p-level
Acquisition (age in years)	Turkish	2.28 (0.77)	$Z = -4.53, N = 32, p < 0.0001$
	German	7.25 (6.16)	
Directly measured proficiency			
Proficiency (mean Z-score)	Turkish	0.02 (0.75)	$T(30) = 0.18$, n.s.
	German	−0.005 (0.70)	
Read a story (words/min)	Turkish	103.6 (16.3)	$T(30) = -11.06, p < 0.0001$
	German	174.8 (37.0)	
Word fluency (words/min)	Turkish	34.44 (11.20)	$T(31) = 0.73$, n.s.
	German	33.19 (7.74)	
Build sentences (correct of max 10)	Turkish	7.26 (2.19)	$T(30) = -0.94$, n.s.
	German	7.68 (1.99)	
Self-rated proficiency			
Mean proficiency	Turkish	2.05 (0.56)	$Z = 4.01, N = 32, p < 0.0001$
	German	1.39 (0.43)	
Speaking	Turkish	2.19 (0.64)	$Z = 4.18, N = 32, p < 0.0001$
	German	1.41 (0.50)	
Reading	Turkish	1.97 (0.59)	$Z = 3.75, N = 32, p < 0.001$
	German	1.31 (0.47)	
Writing	Turkish	2.19 (0.78)	$Z = 3.42, N = 32, p < 0.001$
	German	1.53 (0.57)	
Understanding	Turkish	1.84 (0.63)	$Z = 3.71, N = 32, p < 0.001$
	German	1.31 (0.47)	

Self-rated proficiency in speaking, reading, writing, and understanding was measured for each language by questionnaire using a 4-level scale (1 = perfect, 2 = good, 3 = sufficient, 4 = hardly).

Table 5
Means and standard error means in accuracy (%) and response times of correct responses in milliseconds (RT) across tasks, visual half-fields, acquisition and groups

	Word matching GERMAN		Word matching TURKISH		Face recognition	
	LVF	RVF	LVF	RVF	LVF	RVF
Means and standard error means in accuracy (%)						
Bilinguals (all)	91.39 (1.55)	94.83 (1.00)	92.30 (1.05)	95.61 (0.68)	86.67 (1.26)	75.82 (1.96)
Early (0–5)	91.75 (2.23)	95.48 (1.18)	92.56 (1.53)	96.46 (0.72)	87.45 (1.20)	78.05 (2.60)
Late (6–32)	90.94 (2.19)	94.04 (1.72)	92.00 (1.47)	94.65 (1.16)	85.73 (2.43)	73.11 (2.93)
Monolinguals	92.44 (1.08)	94.36 (0.80)	–	–	84.75 (1.23)	78.57 (1.14)
Response times of correct responses in milliseconds (RT)						
Bilinguals (all)	981 (47.2)	1008 (51.2)	1006 (49.9)	1011 (45.0)	980 (40.0)	982 (32.7)
Early (0–5)	953 (55.0)	996 (70.3)	983 (71.9)	975 (50.2)	998 (57.6)	1000 (47.2)
Late (6–32)	1015 (81.8)	1024 (77.4)	1033 (70.5)	1052 (78.0)	959 (56.4)	961 (45.5)
Monolinguals	959 (35.1)	947 (38.0)	–	–	889 (27.2)	934 (29.2)

3.2.1.2. Face discrimination. We found a highly significant main effect of VHF in the accuracy of this task ($F(1, 27) = 27.56, p < 0.0001$), with a very strong advantage for the LVF (LVFA). No other main effect and interaction showed significance (all Fs $(1, 27) < 1.20$, ns). Similar to the analysis of the word-matching tasks, no significant effects were present in response times of the face-discrimination task (all Fs$(1, 27) < 1.01$, ns).

3.2.2. FCA in bilinguals compared to monolinguals

3.2.2.1. Word-matching task (German version). Again, we observed a highly significant main effect for the VHF in the accuracy data ($F(1, 72) = 7.74, p < 0.01$), indicating a strong RVFA. However, this effect did not interact with Group ($F(1, 72) = 0.70$, ns). No other main effect or interaction reached significance (all Fs$(1, 72) < 0.70$, ns). No significant effects appeared for the response times (all Fs$(1, 72) < 2.29$, ns).

3.2.2.2. Face discrimination. Analysis of the accuracy data of this task showed a very high significant main effect of the visual half-field ($F(1, 72) = 43.12, p < 0.0001$), indicating a very strong LVFA. No other main effect or interaction reached significance (all Fs $(1, 72) < 3.32$, ns). For the response times, the analysis revealed a significant main effect of VHF ($F(1, 72) = 5.13, p < 0.03$) and a strong trend for an interaction between VHF and Gender ($F(1, 72) = 3.83, P = 0.054$) with males showing a stronger LVFA of 49 ms compared to 9 ms in females. Post hoc t-tests revealed the visual-field difference to be significant only in men ($t(35) = -2.87, p = 0.007$), not in women ($t(39) = -0.61$, ns). This asymmetry pattern is in agreement with the majority of studies reporting gender effects on lateralization. However, it should be noted that this interaction did not take place selectively within one language group. The 3-way interaction between VHF, Gender, and Group was far from significance ($F(1, 72) = 0.06$, ns) indicating a larger LVFA in males

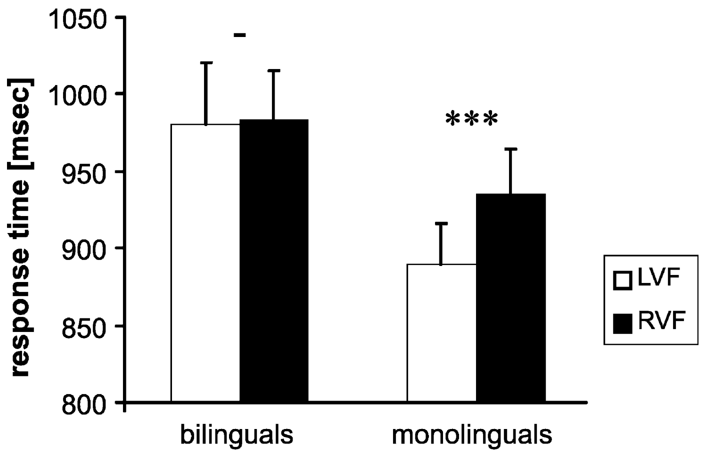

Fig. 1. Significant interaction between Group and VHF in the response times (ms) of the face recognition task. White bars represent the performance for the left (LVF) and black bars for the right visual field (RVF). Post hoc analysis revealed a LVF advantage to be significant only in monolinguals (*** $p < 0.0001$).

for both language groups. Additionally, we observed a significant interaction between 'visual half-field' and 'group' ($F(1,72) = 4.51, p < 0.05$). The post hoc analysis of this interaction revealed a LVFA to be significant only in monolinguals ($T(44) = 4.31, p < 0.0001$), whereas in bilinguals it was not significant ($T(44) = -0.10$, ns) (see Fig. 1). Moreover, post hoc analysis showed a marginally significant group difference in the LVF towards faster response times in monolinguals ($T(74) = 1.96, p = 0.053$), whereas both groups did not differ in the response times of the RVF ($T(74) = 1.10$, ns).

3.3. Relationship between FCAs, acquisition and proficiency in bilinguals

The only robust relationship appeared for the accuracy data between the AIs of the Turkish and the German version of the word-matching task ($r(31) = 0.59, p < 0.001$), explaining about 35% of variance. A strong hemispheric asymmetry in the accuracy data of the Turkish version of the word-matching task was significantly related to a strong hemispheric asymmetry in the German version of this task in bilinguals. Corresponding analyses for both visual half-fields separately, showed a significant positive relationship between the Turkish and the German version of the task for the LVF ($r(31) = 0.64, p < 0.001$) and, on a marginal level, for the RVF ($r(31) = 0.37, p < 0.05$). No further significant relationships, particularly between the AIs and proficiency or acquisition, appeared.

4. Discussion

Our data indicate that Turkish–German bilinguals show no differences in the FCA between both languages. Furthermore they demonstrate that the functional organization of both languages are highly related to each other, and that bilinguals and monolinguals did not significantly differ in their asymmetry patterns for the German language. Thus, these results support the notion that bilinguals and monolinguals exhibit a very similar left hemisphere dominated cerebral organization for verbal functions.

However, the results make it likely that the lateralization patterns in non-verbal functions differ between bi- and monolinguals. We clearly could show that the asymmetry patterns in response times of a face-discrimination task differed between both groups. Monolinguals showed the typically LVFA in accuracy as well as in response time, whereas bilinguals failed to show the LVFA in the response time data of this task. Specific aspects of neuronal processing in a specific visual half-field task are measured by accuracy and response times. These neuronal processes are task-specific and partly asymmetrically organized. Although it is unknown which aspects of the word matching task are responsible for the accuracy/RT difference, they occurred consistently in previous studies (Hausmann & Güntürkün, 1999, 2000; Hausmann et al., 2003). Moreover it should be noted that it is particularly the performance in the LVF, corresponding to the task-related specialized right hemisphere, in which both groups differed. The results suggest that differences in the FCA of other than verbal functions are observable in bilingual subjects.

The observation that the lateralization patterns of right-hemispheric non-verbal functions in bilinguals could be affected is supported by other studies. Unfortunately, as we noted in Section 1, there are only few studies investigating hemispheric asymmetries of other than verbal functions in bilingual subjects. However, similar to Sewell and Panou (1983) and Panou and Sewell (1984), who investigated hemispheric asymmetries for other left-hemispheric verbal and right-hemispheric non-verbal tasks in bilinguals and congenital deaf subjects, the Turkish–German bilinguals subjects of this study showed a left-hemisphere advantage for the processing of abstract nouns irrespective of language of testing, but an absence of asymmetry in the response times in the non-verbal face discrimination task. In agreement with our results, both studies showed that the monolingual subjects had displayed the usual left-hemisphere advantage for verbal material, and a consistent right-hemisphere advantage on the non-verbal task. However, although all groups had a consistent RVFA in the verbal task, in one of these studies (Sewell & Panou, 1983), the bilingual subjects showed a reduced lateralization for their second language in comparison with their native language. That is in contrast to our results, which not only show that the hemispheric asymmetries in Turkish–German bilinguals did not differ between both languages, but even that these asymmetries are highly correlated with each other.

Although the origin of this difference remains unclear, it seems not to have resulted from possible differences in age of acquisition or proficiency of the bilingual groups tested by these studies. We clearly showed that the age of language acquisition as well as the proficiency did not affect the functional cerebral asymmetry. This is in contrast to the assumption by Chernigovskaya, Balonov and Deglin (1983), cited in Hamers and Blanc (2000), who supposed a differential lateralization in early versus late bilinguals. However, this result is in agreement with the majority of imaging data, which found a similar pattern of overlapping activations in early and late bilinguals (Chee et al., 1999; Klein et al., 1995). Although it is suggested that spatially overlapping networks to process first and second language should not immediately be equated with task performance (Perani et al., 1998), behavioural data of this study gives no hint that proficiency affects the cortical representation and processing of the second language. Differences in functional cerebral organisation in bilinguals seems to be especially pronounced when low proficient bilinguals are investigated (Dahaene et al., 1997). A missing effect of proficiency on functional organisation in this study might be due to the fact that all German–Turkish bilinguals were highly proficient in both languages.

Another study that investigates the influence of language experience and the performance on different right-hemisphere tasks in Arabic–Hebrew bilinguals (Eviatar, 1997) does not support the hypothesis that multilingualism can affect the manner in which these non-language tasks are subserved by the right hemisphere. Unfortunately, Eviatar's study did not measure FCA in verbal tasks. This is of special interest because in this study Arabic-Hebrew bilinguals with right-to-left reading and writing habits were investigated. Although there is support that readers of right-to-left also show the typical left-hemisphere advantage in verbal tasks (Bradshaw, Nettleton, & Taylor, 1981; Faust, Kravetz, & Babkoff, 1993), we can not rule out the possibility that right-to-left reading bilinguals differ in their functional cerebral organization from bilinguals with left-to-right scanning habits. Although we did not control the potential effects of scanning habits, we clearly showed that bilingualism may affect the access or availability of right-hemisphere abilities at least in subjects with a left-to-right reading and writing direction.

Our data support the view that learning a second language does not alter language asymmetry. Thus, mono- and multi-linguals are probably located on different levels of the same cerebral language system continuum (Paradis, 2000). However, our study makes it likely that learning a second language with high proficiency alters the neuronal arrangement of a non-language system. At this stage it is rather speculative which neuronal changes are responsible for this effect. It is conceivable that the acquisition of a second language leads to substantial modifications in various cortical areas, and thus affect cerebral organisation of other functional domains—potentially by synaptical competition. Why only response times in the face-discrimination task are affected by these modifications remains unclear.

The overall conclusion to emerge from this investigation is that the functional cerebral organisation of bilinguals can differ and deviate from monolingual controls without showing differences in the FCA of verbal functions, rather affecting lateralization in non-verbal functions which are mainly processed by the right hemisphere. The extent to which these deviations in bilinguals are task specific remains unclear. Further studies are needed to test the generality of these findings in other experimental tasks which are not restricted to language processes but are known to show a right hemisphere advantage.

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