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Stability of right visual field advantage in an international lateralized lexical decision task irrespective of participants' sex, handedness or bilingualism

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Abstract

In lateralized lexical decision tasks, accuracy is higher and reaction times are faster for right visual field (RVF) than left visual field (LVF) presentations. Visual field differences are thought to demonstrate the left hemisphere's dominance for language. The use of different tasks and words between studies and languages make direct comparisons difficult. We performed a lateralized lexical decision task for which we selected 4-6 letter words that are used in three languages of Switzerland (French, German, and Italian) and English and Dutch. We accounted for the potential moderating roles of sex, handedness, and multilingualism (early acquisition versus late acquisition of at least one second language). One hundred participants were tested at a French-speaking University in Switzerland. All performed a French vocabulary knowledge task (Brysbaert, 2013). Results showed a RVF over LVF advantage (accuracy, reaction times, signal detection theory measures) for all groups, i.e. irrespective of participants' sex, handedness and how many languages they spoke. We observed, however, that enhanced vocabulary knowledge related to a right hemisphere shift in early bilinguals and a left hemisphere shift in late bilinguals. We discuss how the current observations can inform future studies suitable for the validation of the current task using an "international" vocabulary.

Keywords: Lexical decision task, hemispheric lateralization, asymmetry, European languages, bilingual

Introduction

Hemispheric specialization or “cerebral dominance” for a variety of cognitive functions has long been described from clinical observations on patients with unilateral cerebral lesions. For instance, in the mid-1800s, clinical studies showed that the left hemisphere (LH) is “dominant” for language (Broca, 1865; Wernicke, 1874). Other clinical examples indicated that the right hemisphere (RH) is dominant for functions such as face-identification (Hoff & Pötzl, 1937) and topographic orientation (Hughlin Jackson & Gowers, 1875). Today, the LH dominance for language and the RH dominance for spatial processing are the most reliably observed lateralized cognitive functions. As summarized recently, “Empirically, there are no other processes that have produced such reliable differences between the hemispheres as experiments on language (e.g., lexical decision) and spatial (e.g., mental rotation) tasks” (Hugdahl, 2000, p. 217). While the origins of functional hemispheric specialization (including handedness) remain to be determined (Bradshaw, 1988; Hugdahl, 2000; Ocklenburg, Beste, Arning, Peterburs, & Güntürkün, 2014) studies that assess its stability (Blumstein, Goodglass, & Tartter, 1975; Chiarello, Dronkers, & Hardyck, 1984; Teng, 1981; Voyer, 2003), short-term and long-term fluctuations (Bayer & Hausmann, 2009; Cabeza, 2002; Hausmann & Gunturkun, 2000; Mohr, Michel, et al., 2005), clinical relationships (Eyler, Pierce, & Courchesne, 2012; Grimshaw & Carmel, 2014; Mitchell & Crow, 2005) and individual difference relationships (Hausmann & Gunturkun, 1999; Mikheev, Mohr, Afanasiev, Landis, & Thut, 2002; Nicholls, Orr, & Lindell, 2005) require that its experimental assessment is reliable and valid (Voyer, 1998).

Phil Bryden (a complete bibliography can be found in the *Laterality* obituary) (McManus, Corballis, & Bulman-Fleming, 1996) importantly contributed to the determination of such reliable and valid tools. He dedicated much of his academic life "to explicate the implications of perceptual and perceptual-motor asymmetries in normal individuals for models of hemispheric specialization" (Bulman-Fleming & MacKinnon, 1998, p. 100). In non-clinical populations, Phil Bryden and other researchers frequently tested hemispheric specialisation for functioning by opting for non-invasive paradigms such as the visual half-field technique (Beaumont, 1982; Bourne, 2006; Hunter & Brysbaert, 2008) and dichotic listening paradigms (e.g. Bryden, 1965; Bryden 1986; Kimura, 1961). In fact, Phil Bryden and Doreen Kimura (both at McGill University at the time) are considered to have "established the laterality industry that was built on these two techniques" (McManus et al., 1996, p. 258). In tachistoscopic paradigms, stimuli are briefly presented to the right (RVF) and left (LVF) visual field. In dichotic listening paradigms, sounds are presented simultaneously to the right and left ear. In the case of linguistic material, information presented to the RVF/right ear as compared to LVF/left ear commonly yields a processing advantage (accuracy and reaction times). This laterality bias is thought to reflect the LH's advantage for language, because information presented to RVF / right ear is initially sent to the LH and information presented to LVF / left ear is initially sent to the right hemisphere (RH).

The behavioural paradigms in non-clinical populations were initially used as behavioural assessments in split-brain patients, patients with focal epilepsy, hemispherectomized patients or patients with callosal agenesis (Gazzaniga, Bogen, & Sperry, 1965; Kimura, 1961; Lassonde & Bryden, 1990; Lassonde, Bryden, & Demers, 1990; Sperry, 1982). The paradigms have created both enthusiasm (Geffen & Caudrey, 1981; McKeever, 1971) and disenchantment (Efron, 1990; Orenstein, 1976; Teng, 1981). The paradigms created enthusiasm, because hemispheric specialization could be assessed widely and non-invasively in the laboratory. The paradigms created frustration, because results were not unequivocally showing the expected hemispheric asymmetries. Moreover, the consistency with which half-field studies showed lateralized performance within and between studies was disappointing. This was true when the same study used similar lateralized paradigms (Bryden, 1965; Fennell, 1977), the same study used different lateralized paradigms (Boles, 2002; Hellige et al., 1994), or the same paradigm was assessed repeatedly over time (Blumstein et al., 1975; but see Chiarello et al., 1984).

To limit the possibility that inconsistencies were influenced by methodological shortcomings, various researchers provided guidelines on how best to perform such behavioural half-field paradigms (Beaumont, 1982; Bourne, 2006; Hunter & Brysbaert, 2008). When such guidelines were followed, behavioural laterality measures and neuroimaging measures correlated nicely. For example Hunter and Brysbaert (2008) reported significant positive correlations between laterality indices as measured by visual half-field paradigms and fMRI in word (r =. 63) and picture naming (r = .77). Such recent studies revived the notion that results from behavioural half-field paradigms should be taken seriously in the theoretical and clinical domain (Carey & Johnstone, 2014; Hugdahl, 2011; Van der Haegen, Cai, Seurinck, & Brysbaert, 2011; see also Van der Haegen, Westerhausen, Hugdahl, & Brysbaert, 2013, for validation evidence with respect to dichotic listening).

While accepting the merits of behavioural paradigms, we still face experimental challenges. For instance, despite its extensive use, we are not aware of standard half-field paradigms that have been validated across populations and research questions. If at all described in sufficient detail, the methodological details vary widely between studies (Beaumont, 1982; Bourne, 2006; Hunter & Brysbaert, 2008), the full verbal materials (words, nonwords and their combinations) are often not published (e.g. Bryden & Rainey, 1963; Hausmann & Gunturkun, 1999; Howell & Bryden, 1987; Mohr, Krummenacher, et al., 2005) and differences between languages can make a direct comparison between studies, cultures and languages difficult (e.g. Bless et al., 2015; Ibrahim & Eviatar, 2012). Moreover, countries differ as to whether people speak one or several languages and / or consist of neighbouring and overlapping areas for which different languages dominate (e.g. Belgium, Switzerland). In such countries, bilingualism, if not multilingualism, is common often from early age. Given that several studies suggested atypical hemispheric asymmetry in bilinguals, especially when the second language was acquired early (by the age of 6 years, e.g. Chee, Tan, & Thiel, 1999; Hull & Vaid, 2007), measuring language lateralization for one language might not work for all people of this country alike.

The current study is the first report on a lateralized half-field paradigm using phonologically similar and semantically identical words existing in three of the four national languages of Switzerland (German, French, Italian) and two additional languages (English, Dutch). Participants were recruited in the French speaking part of Switzerland. They had to make lexical decisions to 4 and 6 letter words and nonwords presented visually on a computer screen. To account for the role of multilingualism (e.g.

Hull & Vaid, 2007) and handedness (e.g. Bryden, 1965; Knecht et al., 2000), we collected data from right-handed and non-right-handed students comparing performance between early (by the age of 6 years) and late (> 6 years of age) bilinguals (or multilinguals) (see also Chee et al., 1999; Hull & Vaid, 2007). We tested whether our words resulted in a RVF over LVF advantage, and whether this visual field advantage would be more pronounced in men (e.g. McGlone, 1980; Shaywitz et al., 1995), individuals learning at least a second language later in life (Hull & Vaid, 2007), and right-handers (e.g. Bless et al., 2015; Brysbaert, 1994).

Method

Participants

We recruited 113 participants (81 women) through personal contact, classroom advertisement and public advertisement in and around the University of Lausanne, situated in the French-speaking part of Switzerland. Of these, 71 participants were randomly recruited from the first year psychology subject pool. The remaining participants were preselected via personal contact and public advertisements for their handedness or bilingualism (respectively multilingualism). These remaining participants were remunerated for their participation. Through this procedure, we were able to recruit 81 right-handers and 32 left-handers (handedness assessment see below) as well as two groups of individuals who, according to self-report, acquired their second (or more) language(s) early (by the age of 6 years) or late (> 6 years of age, see data analysis section for further details). All participants had normal or corrected to normal vision. As indicated by self-report, none of the participants reported a history of drug abuse (either recreational or psychiatric) in the past three months, or a previous history of psychiatric or neurological illness. After having received written study information, the participants provided written informed consent prior to participation. The study was conducted in accordance with the guidelines of the declaration of Helsinki (World Medical Association, 2001).

Materials

Self-report questionnaires.

Demographic information, multilingualism and language vocabulary test. A first questionnaire assessed demographic information (e.g. gender, age, health, languages spoken). In addition, we assessed participants' vocabulary knowledge with LEXTALE (www.lextale.com), a Lexical Test for Advanced Learners of English (Lemhöfer & Broersma, 2012), yet, applied here in its French version (Brysbaert, 2013). We administered it on paper. Participants saw 84 letter strings and had to indicate which word they knew (Brysbaert, 2013). Of the 84 letter strings, 56 were actual French words of varying difficulty and 28 were French-looking nonwords. The number of correct answers was summed. Accordingly, the LEXTALE scores ranged from 0 to 84 with higher scores reflecting superior vocabulary knowledge. In this section, we also asked participants about their language skills, i.e. their mother tongue, which further languages (up to three more languages) they speak, and at what age they had acquired them.

Edinburgh Handedness Inventory. The Edinburgh Handedness Inventory is a well-established handedness questionnaire (Oldfield, 1971). For 10 activities, individuals had to indicate their preferred hand use, i.e. they reported which hand they preferably use for given activities such as writing, holding a pair of scissor, or brushing their teeth. They judged the strength of hand use through one or two crosses. One cross indicates general hand preference and two crosses indicate an exclusive use of a given hand (would not use the other hand for this activity apart from having no other choice at all). In the case of ambidexterity, participants gave one cross for each hand. We calculated the following laterality index: ((sum of right hand crosses – sum of left hand crosses) / sum of all crosses) *100. Thus, scores ranged from -100 to 100 with negative values indicating a left hand preference and positive values a right hand preference (including zero) (Arning et al., 2013; Nicholls, Thomas, Loetscher, & Grimshaw, 2013). Based on the laterality index, participants were allocated to one of the following groups: left-handers (LI's between -100 and -50), mixed-handers (LI's between -50 to 50), and right-handers (LI's between 50 to 100).

Lateralized Lexical Decision Task (LDT).

Word selection. To mirror the Swiss language landscape, we initially aimed to select words that exist in three of the four national languages (French, German, Italian). To additionally be of wider use, the words should also exist in English. We started our word selection from a database of 1700 words existing in the English and Dutch vocabulary (Marc Brysbaert, Ghent, Belgium). To select words suitable for the tachistoscopic half-field procedure, we kept words consisting of 4, 5 or 6 letters. Using the online Leo dictionary (http://dict.leo.org/, 2012), we tested for each word whether it exists in French, German, Italian, and English. By default, these words exist in Dutch as well. This final criterion left us with 280 words.

Word frequencies. For these 280 words, we calculated word frequency and word imageability for English and French using respectively N-Watch (Davis, 2005) and

Lexique 3.80 (New, Pallier, Brysbaert, & Ferrand, 2004). Unfortunately, the English and French word frequency values cannot be directly compared. English word frequency reflects the word's total CELEX database frequency (Baayen, Piepenbrock, & Gulikers, 1995) as reported in N-Watch (Davis, 2005). French frequency was given as the mean frequency with which a word occurred in millions of spoken and written words (New et al., 2004). Because of these differences in word frequency determination, we compared word frequencies between languages according to their quartiles. After having determined for each language and word database each word's frequency, we created quartiles for the word frequencies of each language. We retained words that fell into the same quartile for the English and the French word frequency distribution. To avoid words of very low frequency, we kept words that fell into the 2nd, 3^{rd,} or 4th quartile leaving us with 16 lowercased words: *agenda, alibi, aura, casino, film, gala, garage, jazz, jury, menu, radio, piano, snob, studio, taxi, virus* (see word frequencies in Appendix Table A1).

We refrained from applying this word frequency procedure to German and Italian, because each further selection criterion reduced the number of words to be retained. Given that we were left with 16 words at this stage, we decided to use these words for the current lateralized lexical decision task, testing for differences between languages at a later stage. Controlling for French and English word frequencies, we ensured that word frequency was controlled for English (the dominant language in research environments) and French (dominant language in local environment). Local native speakers confirmed that the 16 remaining words were also common words in German and Italian.

Nonword stimuli creation. For each of the 16 words, we determined one nonword using the pseudoword creator "Wuggy" (Keuleers & Brysbaert, 2010) (for the actual task material, see Appendix) to create word-nonword pairs. A priori, we selected nonwords that differed from the corresponding word by two letters. Moreover, these nonwords had to have relatively low values on the OLD20 scale and the MaxDeviation scale. By inference, each nonword had a relative dense neighbourhood of possible words (lower score on OLD20) and small differences between subsyllabic segments in the word and nonword (lower score on MaxDeviation) (Keuleers & Brysbaert, 2010). Finally, to create nonword-nonword pairs, we chose for each word the nonword listed second (based on above criteria) on the Wuggy-created nonword list. The other nonword for the nonword-nonword pair was the next nonword in the respective list for which two letters differed from the other nonword (Appendix Table A2). Thus, we applied analogue selection criteria for words and nonwords, and had letter string pairs having the same number of characters.

For the actual LDT procedure, we prepared the following LVF/RVF letter string combinations: word/nonword (16 pairs), nonword/word (16 pairs) and 32 nonword/nonword pairs (the 16 original nonword/nonword pairs were also shown in reversed order).

LDT procedure. For each lexical decision trial, we presented one letter string pair, one stimulus to the RVF and the other to the LVF. All letters were written in a black Courier New font (12 points, black, lowercased) and presented on a computer screen on white background. Per trial, we first presented a fixation cross for 1000 ms. After its disappearance, the letter string pair appeared for 100 ms. Participants had 2000 ms to respond. If no response was given, the next trial was initiated. We presented each letter string combination four times in randomized order. The experiment was programmed using DMDX (Forster & Forster, 2003). Participants were seated in front of a computer screen with a screen-eye distance of 57 cm, so that 1 cm corresponds to 1° of visual angle. Thus, the eccentricity of each string was from 2° to 5° of visual angle horizontally and the height of letters was 0.5° of visual angle. The full list of word and nonword combinations can be found in Table A2 of the appendix. Moreover, we provide the DMDX script and an R script for analysis on request.

Participants were instructed to indicate by button press whether they saw a meaningful word to the left (respond with left index finger on a left-sided button), right (respond with right index finger on a right-sided button) or saw no meaningful word on either side (press space bar with both thumbs). Prior to the first experimental trial, participants performed 10 practice trials with stimuli not used in the actual experiment. Subsequently, they performed a total of 256 trials with a self-paced break in the middle. Participants were instructed to respond as fast and accurately as possible. They were instructed to fixate the fixation cross at all times. We assessed the number of correct lexical decisions and the mean reaction times for correct word decisions for LVF and RVF separately.

Overall procedure. After having received detailed study information, participants signed the written informed consent form. Subsequently, they filled in the self-report questionnaires before being led to a light and sound controlled individual testing room. Here, they received detailed written information on the LDT task, and could ask further questions if needed. Otherwise, they were left in the testing room and were asked to return when finished. At the end, participants were fully debriefed and could ask further questions. One testing session took about 30 – 45 minutes.

Data Analysis

We removed one participant who provided no demographic information, 3 participants (2 female right-handers, 1 male mixed-hander) who scored low in both the RVF and LVF (< 25 (out of 64 possible) correct responses each), 2 participants who performed nonword responses (space bar) never (1 female right-hander) or only once (1 male mixed-hander), and 7 participants (6 women, 6 right-handers, 1 mixed-hander) for whom i) none of our 5 languages was the mother tongue and ii) none of our 5 languages was acquired at or before the age of 6 years. We retained the final 100 participants for analysis[1].

For the lexical decision data, in line with previous studies (Allison, Puce, & McCarthy, 2000; Cornelissen, Tarkiainen, Helenius, & Salmelin, 2003; Ratcliff, Gomez, & McKoon, 2004), we excluded individual response latencies that were faster than 200 ms. Those slower than 2000 ms were automatically excluded, because 2000 ms was the maximal response time (see LDT procedure). This resulted in the exclusion of 46 individual trials across all participants.

For the analysis, we performed two sets of analysis. The first set consisted of analyses we conventionally see in laterality research. We analysed the number of correct word decisions and RTs for correct word decisions. The second set accounted for overall performance, i.e. not taking only hit rate but also false alarm rate into account. In particular, we determined the signal detection theory measures 1) d-prime (sensitivity)

[1] To note, among these 100 participants, two had reported cannabis use and three were above the age of 30 years. When performing the below described analyses with and without these participants, the results remained the same. We thus kept these participants for analyses.

and 2) the response criterion C (the observer's response bias (Gescheider, 1997; Green & Swets, 1966), for each visual field separately. Hits were summed for each visual half-field separately (hits for e.g. RVF: a word was shown to the RVF and the participant gave a right response). False alarms were also summed for each visual field separately (false alarms for e.g. RVF: a nonword was shown to the RVF and the participant falsely gave a right response). Sensitivity was calculated separately for each visual field as *d-prime* = z(% hit) - z(% false alarm). Response biases were calculated separately for each visual field as *C-biases* = -1/2 * (z(% hit) + z(% false alarm)). The 'z' indicates z-normalized data. Higher d-primes indicate better stimulus detection sensitivity, i.e. a sensitivity that is uncontaminated by how an observer applies a decision criterion. Lower C-biases indicate a stricter response tendency (less false alarms) and higher C-biases reflect a looser response tendency (more false alarms, YES answer tendency), thus, the observer's decision criterion.

Komogorov-Smirnov tests of normality showed that accuracy and RTs measures were normally distributed, apart from accuracy for RVF performance (p = .007). The signal detection measures were not normally distributed (p-values > 0.05), apart from C-biases for the RVF (p = 0.20). Also, age, the handedness index score and the LEXTALE scores were not normally distributed (p-values < .001). Accordingly, measures involving d-primes, C-biases and the latter three variables were performed using nonparametric comparisons.

For accuracy and RTs measures, we performed repeated measures ANOVAs with visual field as repeated measure and sex as between subject factor. We performed analogue ANOVAs with handedness groups or multilingualism groups (early versus late acquisition) as alternative between subject factors. For signal detection measures, we used Mann-Whitney U tests (two samples) and Kruskal-Wallis H tests (three samples) for unpaired comparisons.

To account for degree of lateralization as a function of lexical knowledge, we correlated the LEXTALE scores with the LDT measures per visual field using Spearman's rho correlations.

All *p*-values were two-tailed and the *α*-level was set at .05, unless otherwise stated. Effect sizes (partial eta-squared, η_p^2) are reported for all ANOVA results.

Results

Participants

The 100 participants had a mean age of 21 years (range 18 – 53 years) (Table 1). According to Mann-Whitney U-tests, the sexes did not differ for age (U = 926.00, p = .523), handedness index scores (U = 979.00, p = .823), and LEXTALE scores (U = 782.50, p = .083) (Table 1). Moreover, the number of women and men were comparable for the two handedness groups (21 women out of 29 left-handed participant, 51 women out of 71 right-handed participants, $\chi2$ = .003, df = 1, p = .953), for the three handedness groups (15 women out of 19 left-handed participants, 15 women out of 24 mixed-handed participants, 42 women out of 57 participants, $\chi2$ = 1.609, df = 2, p = .447), and for early and late multilingual groups (14 women out of 18 participants in the early group and 58 women out of 82 participants in the late group; $\chi2$ = .363, df = 1, p = .547).

LDT Lateralization

In average (±*SD*), across the 256 trials, participants indicated 58.34 times (± 18.10, range 14 to 99) that they saw a word on the left, 78.04 times (± 19.787, range 37 to 152) that they saw a word on the right, 107.41 times (± 29.749, range 19 to 171) that they saw no word on either side, and 12.45 times (± 14.711, range 1 to 80) no response was registered. Given that 64 words were shown on the right and 64 words on the left, the usefulness of signal detection measures (accounting for false alarms) is nicely demonstrated.

LDT Lateralization and Sex

The repeated measures ANOVA on accuracy showed a significant main effect of visual field, F(1,98) = 77.425, $p < .001$, $\eta_p^2 = .441$. Performance was superior for RVF than LVF performance (Table 1). The main effect for sex and the interaction between visual field and sex were not significant (smallest $p = .160$) (Table 1). Likewise, the analogue ANOVA on RTs showed a significant main effect of visual field, $F(1,98) = 31.200$, $p < .001$, $\eta_p^2 = .241$. Response time of correct responses was faster for RVF than LVF trials (Table 1). The main effect for sex and the interaction between visual field and sex were not significant (smallest $p = .445$) (Table 1). While sex comparisons were not significant for d-prime (smallest $p = 0.830$), C-biases tended to be higher in men than women (RVF: $U = 776.00$, $p = 0.075$; LVF: $U = 785$, $p = 0.087$) (Table 1).

Table 1. *Means (± 1 SD) for age (in years), handedness index scores, LEXTALE scores and LDT performance measures (accuracy, RTs, d-prime, C-bias) for the RVF and LVF separately. Values are provided for the total sample and the sexes separately.*

Group	Total Sample	Women (n = 72)	Men (n = 28)
Age	21.42 ± 4.73	21.67 ± 5.48	20.79 ± 1.50
Handedness	34.85 ± 65.53	33.36 ± 66.88	38.70 ± 62.96
LEXTALE	71.39 ± 8.90	71.13 ± 8.15	72.07 ± 10.72
Accuracy RVF	48.01 ± 9.36	48.74 ± 9.26	46.14 ± 9.53
Accuracy LVF	34.42 ± 11.26	35.06 ± 11.99	32.79 ± 9.12
RT RVF	763 ± 99	761 ± 97	767 ± 106
RT LVF	843 ± 126	857 ± 128	832 ± 123
d-prime RVF	2.19 ± 0.59	2.19 ± 0.60	2.18 ± 0.57
d-prime LVF	1.53 ± 0.63	1.53 ± 0.68	1.53 ± 0.47
C-bias RVF	0.27 ± 0.29	0.23 ± 0.28	0.35 ± 0.30
C-bias LVF	0.60 ± 0.29	0.57 ± 0.30	0.67 ± 0.25

LDT Lateralization and Vocabulary Knowledge

Spearman correlations between the LEXTALE scores and LDT measures showed that accuracy was higher (RVF: $r = .346$, $p < .001$; LVF: $r = .244$, $p = .014$) and responses were faster (RVF: $r = -.228$, $p = .023$; LVF: $r = -.194$, $p = .053$) with increasing LEXTALE scores. D-primes were higher (RVF: $r = .356$, $p < .001$; LVF: $r = .197$, $p = .050$) and C-biases tended to be lower with increasing LEXTALE scores (at least in the RVF: $r = -.194$, $p = .054$; LVF: $r = -.114$, $p = .257$).

According to Steiger's Z-tests (Hoerger, 2013), the correlation coefficients did not differ for correlations between LEXTALE scores and LVF or RVF performance, respectively (accuracy: Z_H = .832, p = .405; RTs: Z_H = -.319, p = .750; d-prime: Z_H = 1.415, p = .157; C-bias: Z_H = -.690, p = .490).

LDT Lateralization and Handedness

We performed two sets of analyses, one on two handedness groups (left-handers, right-handers) and one on three handedness groups (left-handers, mixed-handers, right-handers). While the main effects of visual field were again significant (results, see *"LDT Lateralization and Sex"),* the main effects for handedness groups and the interactions between visual field and handedness groups were not significant (smallest p = .134) (Table 2). For signal detection measures, the two handedness groups did not differ in sensitivity (d-prime) or response bias (C-bias) (smallest p = .441). In the case of three handedness groups, Kruskall-Wallis tests showed that the three handedness groups did not differ in sensitivity (d-prime), $\chi 2$ = 1.895, p = .388, and response bias (C-bias), $\chi 2$ = .146, p = .930 for RVF presentations,. For LVF presentations, Kruskall-Wallis tests showed that the three handedness groups differed for d-prime, $\chi 2$ = 7.055, p = .029, and on a statistical trend level also for C-biases, $\chi 2$ = 5.001, p = .082. Single comparisons indicated that for both measures the mixed-handed group differed from the right-handed group (d-prime LVF: U = 464.00, p = .023; C-bias LVF: U = 493.00, p = .048) and left-handed group (d-prime LVF: U = 125.00, p = .012; C-bias LVF: U = 142.00, p = .035), respectively (Table 2). The mixed-handed group had higher C-biases and lower d-primes than the other groups (see also Table 2 for means). The right-handed and left-handed groups did not differ from each other (d-prime LVF: U = 508.00, p = .688; C-bias LVF: U = 531.00, p = .900).

Table 2. *Means (± 1 SD) for lateralized lexical decision task measures (accuracy, reaction times (RTs), d-prime, C-bias) for LVF and RVF performance.*

Grouping	Two handedness groups		Three handedness groups		
	RiHa (*n* = 71)	LeHa (*n* = 29)	RiHa (*n* = 57)	MiHa (*n* = 24)	LeHa (*n* = 19)
Accuracy					
RVF	47.73 ± 9.42	48.69 ± 9.35	48.02 ± 9.34	47.08 ± 9.28	49.16 ± 9.89
LVF	34.44 ± 11.62	34.38 ± 10.54	35.26 ± 11.79	29.92 ± 11.01	37.58 ± 8.42
RT					
RVF	760.77 ± 87.00	767.80 ± 125.57	762.18 ± 87.70	754.42 ± 87.54	775.30 ± 141.54
LVF	840.24 ± 119.76	849.35 ± 142.08	846.71 ± 123.64	843.51 ± 114.75	830.60 ± 150.63
d-prime values					
RVF	2.15 ± .57	2.27 ± .65	2.17 ± .59	2.10 ± .48	2.37 ± .71
LVF	1.52 ± .64	1.56 ± .60	1.56 ± .67	1.30 ± .54	1.75 ± .53
C-bias values					
RVF	0.27 ± .29	0.25 ± .31	0.27 ± .29	0.29 ± .27	0.24 ± .33
LVF	0.59 ± .30	0.61 ± .27	0.57 ± .30	0.69 ± .31	0.55 ± .22

Note: Performance is shown when the population is grouped into two handedness groups of right-handers (RiHa) and left-handers (LeHa) as well as into three handedness groups of RiHa, LeHa and mixed-handers (MiHa).

LDT Lateralization and Multilingualism Groups

With regard to vocabulary knowledge, the early (71.61 ± 5.59) and late (71.05 ± 10.07) multilingual individuals did not differ in LEXTALE scores (U = 655.00, p = .455). For the two handedness groups, there was one left-hander and 28 right-handers in the early multilingual group and 17 left-handers and 54 right-handers in the late multilingual group ($\chi 2$ = 5.860, df = 1, p = .015). For the three handedness groups, there were no left-hander, 5 mixed-handers and 13 right-handers in the early multilingual group, and 19 left-handers, 19 mixed-handers and 44 right-handers in the late bilingual group ($\chi 2$= 5.194, df = 2, p = .075).

The repeated measures ANOVAs showed significant main effects of visual field (results, see *"LDT Lateralization and Sex")*. The main effects for multilingualism groups (early, late) and the interactions between visual field and multilingualism groups were not significant (smallest p = .288) (Table 3). The multilingualism groups did not differ for signal detection theory measures (smallest p = .266) (Table 3).

Spearman correlations between LDT performance measures and LEXTALE scores for the two language groups separately showed different effects. For the early group, enhanced LEXTALE scores correlated with enhanced LVF (RT: r = -.474, p = .047; accuracy: r = .465, p = .052), but not RVF (RT: r = -.276, p = .268; accuracy: r = .270, p = .278) performance. The correlations with signal detection measures were not significant (p-values > 0.140). For the late group, enhanced LEXTALE scores correlated with enhanced RVF performance (RT: r = -.223, p = .044; accuracy: r = .339, p = .002), but failed significance for LVF performance (r = -.140, p = .210; accuracy: r = .195, p = .079). For signal detection measures, LEXTALE scores correlated with higher d-primes in the RVF (r = .367, p = .001; LVF: r = .170, p = .128). Higher LEXTALE scores tended to be enhanced with lower C-biases in the RVF (r = -.208, p = .061; LVF: r = -.087, p = .440).

Table 3. *Means (± 1 SD) for lateralized lexical decision task measures (accuracy, reaction times (RTs), d-prime, C-bias) for left visual field (LVF) and right visual field (RVF) performance. Performance is shown when the population is grouped according to when at least one second language has been acquired (by the age of 6 years: early; after the age of 6 years: late).*

	Early (n = 18)		Late (n = 82)	
	RVF	LVF	RVF	LVF
Accuracy	48.11 ± 8.46	33.28 ± 10.12	47.98 ± 9.59	34.67 ± 11.54
RT	763 ± 76	871 ± 135	763 ± 104	837 ± 124
d-prime	2.23 ± .62	1.53 ± .56	2.18 ± .59	1.53 ± .64
C-bias	.28 ± .27	.63 ± .29	.26 ± .30	.59 ± .29

Discussion

The current study is the first to report data gathered in a lateralized LDT for an "international" vocabulary, i.e. for words used in three of the four national languages spoken in Switzerland (French, German, Italian) as well as in English and Dutch. We analysed performance as a function of conventional word recognition measures (number of and RTs for correct word recognition decisions) and signal detection theory (d-prime to represent sensitivity, C-bias to represent response bias) (Gescheider, 1997; Green & Swets, 1966). We found RVF over LVF advantages for all LDT measures. With regard to participants' sex, handedness and multilingualism, we observed that i) men as compared to women yielded a slightly reduced response criterion (C-bias) in both visual fields and ii) mixed-handers showed lower d-primes and higher C-biases (see also Grimshaw, Yelle, Schoger, & Bright, 2008; Christman, Henning, Geers, Propper, & Niebauer, 2008) when compared to both right-handers and left-handers, again in both visual fields. In addition, we observed an overall superior LDT performance (higher accuracy, lower RTs, higher d-prime) for both visual fields and a stricter response bias (lower C-biases) for the RVF with increasing vocabulary knowledge as assessed with the French version (Brysbaert, 2013) of LEXTALE (www.lextale.com), a Lexical Test for Advanced Learners of English (Lemhöfer & Broersma, 2012). Moreover, we found that enhanced LEXTALE scores related to better LVF performance (accuracy, RTs) in early bilinguals and to better RVF performance in late bilinguals (accuracy, RTs, d-prime, C-bias).

We suggest that the current paradigm is (methodologically) appropriate to test for a RVF (and by inference LH) advantage for language, at least for a French-speaking population.

We used relatively short words and nonwords of 4 to 6 letters (Bryden, 1986; Howell & Bryden, 1987), presented them tachistoscopically for 100 ms simultaneously to the two visual fields, and performed over 250 trials (see Bourne, 2006; Hunter & Brysbaert, 2008 for advice on such paradigms). We were, however, relatively limited in the control of other factors such as word frequency and imageability. Moreover, the databases we used for words in different languages defined word frequencies in different ways, such as for French and English (see method section). Consequently, we compared word frequencies for English and French according to quartiles. We retained words that fell into the same word frequency quartiles for the respective English and French word (avoiding words that belonged to the lowest frequency quartiles). After this selection procedure, we were left with 16 possible words. If we had aimed to extend this selection procedure to German, Italian and Dutch, it would have been impossible to end up with a sufficient number of words. We are not too worried about this study limitation, because performance advantages of high over low frequency words as well as of high over low imageability words seem comparable for the RVF and LVF (for work by Bryden, see Howell & Bryden, 1987; McMullen & Bryden, 1987; see also Gardner, Rothkopf, Lapan, & Lafferty, 1987; Scott & Hellige, 1998).

Sex played no role in our study, apart from a trend that men showed a less strict response criterion than women in both visual fields. Thus, we did not find that men are more lateralized than women (e.g. McGlone, 1980; Shaywitz et al., 1995). While sex differences have been reported (e.g. Hausmann et al., 1998; Hiscock, Israelian, Inch, Jacek, & Hiscock-Kalil, 1995; Shaywitz et al., 1995; Voyer, 2011), they are not always found (e.g. Sommer, Aleman, Somers, Boks, & Kahn, 2008) revealing only small effects

(Bless et al., 2015; Boles, 2005; Hirnstein, Westerhausen, Korsnes, & Hugdahl, 2013; Hiscock et al., 1994, 1995; Voyer, 2011). Such inconsistencies might partly emerge from methodological and time-sensitive issues (e.g. Mohr, Michel, et al., 2005; Ortigue, Thut, Landis, & Michel, 2005) and partly because sex hormonal factors have been largely ignored (e.g. Cowell, Ledger, Wadnerkar, Skilling, & Whiteside, 2011; Hausmann, Hamm, Waldie, & Kirk, 2013; Hausmann, 2010).

We could have expected (but did not find) right-handers to be more lateralized than non-right-handers (Bless et al., 2015; Brysbaert, 1994; Knecht et al., 2000). Admittedly, these handedness differences are frequently weak (e.g. Bless et al., 2015; Brysbaert, 1994; Ocklenburg et al., 2014) or do not occurr at all (e.g. Chiarello et al., 1984). Potentially, we should have assessed familial sinistrality (McKeever & VanDeventer, 1977; Thilers, MacDonald, & Herlitz, 2007) or confirmed RH and LH dominance for language via brain imaging methodologies (Van der Haegen et al., 2013). An alternative caveat might be the approach to laterality measures. For instance, despite an overall similar asymmetrical performance of right-handers and left-handers in various lateralized tasks (e.g. Hellige et al., 1994), the report of a smaller degree of asymmetry in left-handers as compared to right-handers (e.g. Bless et al., 2015; Hellige et al., 1994) might be a questionable theoretical and methodological approach (Paradis, 2008).

It is reassuring that better vocabulary knowledge correlates with superior lexical decision performance in both visual fields (a link with stricter response criterion emerged for the RVF only). These relationships were, however, shifted toward LVF performance in early multilingualism and toward RVF performance in late multilingualism. Previous studies indicated that early acquisition of at least one more language (by the age of 6 years) might favour bilateral language representations and later acquisition stronger LH dominance (Hull & Vaid, 2007; Klein, Mok, Chen, & Watkins, 2014). Given that not all studies come to this conclusion (our study; Chee et al., 1999), the relationships with vocabulary knowledge might at least partially explain these group differences. Indeed, the meta-analysis on 66 studies by Hull and Vaid (2007) indicated that a LH involvement is most relevant to late learners. In line with their meta-analysis, this LH shift might become even more pertinent when language proficiency is low for the second language.

Finally, we would like to discuss the problem of the variability in the type of studies presented here. While lateralized visual word recognition tasks seem to result in small but acceptable test-retest reliability (Chiarello et al., 1984), such an effect would have to be shown for our LDT task. We did not test an equal number of participants in the different sex, handedness and multilingualism groups, which might have blurred potential group differences. When looking at the results in the various tables, however, we did not observe that the results of the smaller study groups yielded larger variances to those obtained from the larger study groups. Also, future studies should test the validity by comparing language lateralization as measured with the LTD task presented in the current study with related paradigms, such as the well established consonant-vowel dichotic listening task such as intensively tested by the Bergen group (e.g. Bless et al., 2015; Westerhausen, Bless, Passow, Kompus, & Hugdahl, 2015 for recent examples) and the linguistic dichotic listening task developed originally by Bryden and MacRae (1988). In the end, the overall goal would be that basic language lateralization could be tested by one and the same task rather than having to rely on new word selections and procedural adaptations. Moreover, a widely available task might help to account for the question as to whether the degree of lateralization in the LDT task is actually related to the degree of language lateralization and what factors might account for these visual field differences (Weems & Reggia, 2004)

In sum, we report on lateralized performance (accuracy, reaction times, signal detection measures) gathered from a LDT using an "international" vocabulary (words existing in Dutch, English, French, German, Italian). The participants from the French-speaking part of Switzerland showed a RVF over LVF advantage in our task, irrespective of their sex or handedness. Overall, lexical decisions were superior with enhanced vocabulary knowledge. Moreover, early learners of at least a second language (by the age of 6 years) showed a RH shift in LDT performance with enhanced vocabulary knowledge, while such a LH shift was observed in late learners. We conclude that the current paradigm is appropriate to test for a RVF (and by inference LH) advantage for language. Future studies should further validate the task by performing test-retest comparisons, assess native Dutch, English, German and Italian speakers, control for variables such as female's menstrual cycle, balanced population sizes, familial sinistrality, and compare performance with related paradigms (e.g. dichotic listening).

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Appendices

Table A1

List of the 16 words and their respective word frequencies in English and French

	Word frequency	
	English	French
Word	(CELEX)	(Lexique 3.80)
Agenda	8.66	5.55
Alibi	3.46	7.88
Aura	4.8	9.66
Casino	3.74	10.35
Film	88.16	49.53
Gala	0.84	3.14
Garage	22.79	23.32
Jazz	8.49	7.75
Jury	29.11	5.14
Menu	7.26	10.95
Radio	83.97	50.54
Piano	26.03	28.51
Snob	2.29	1.06
Studio	22.01	19.9
Taxi	29.61	41.22
Virus	9.33	15.2

Table A2: Word stimuli and nonword stimuli as presented in pairs in the lateralized lexical decision task. Each pair would be shown in below sequence, but also in the reversed order. The bold stimuli are meaningful words in French, English, German, Italian and Dutch.

Stimuli 1	Stimuli 2
agenda	asenga
alibi	acipi
aura	aita
casino	caniso
film	fitz
gala	dara
garage	lapage
jazz	jaik
jury	jula
menu	besu
piano	pieni
radio	rapoo
snob	ssib
studio	slugio
taxi	taia
virus	gilus
lara	vata
sneg	snik
cadisy	canisi
eure	euta
janz	japt
beny	bevu
asanca	asande
gitus	giris
turnex	turmel
slougou	slougue
vavade	vavege
pueni	peani
juto	jula
taht	tawl
rageu	rapea
firl	fibm