

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

Julie Willemin<sup>a</sup>, Markus Hausmann<sup>b</sup>, Marc Brysbaert<sup>c</sup>, Nele Dael<sup>a</sup>, Florian Chmetz<sup>d,e</sup>, Asia Fioravera<sup>a</sup>, Kamila Gieruc<sup>a</sup> and Christine Mohr<sup>a</sup>

<sup>a</sup>Institute of Psychology, University of Lausanne, Lausanne, Switzerland; <sup>b</sup>Departement of Psychology, University of Durham, Durham, UK; <sup>c</sup>Departement of Experimental Psychology, University of Ghent, Ghent, Belgium; <sup>d</sup>Faculty of Biology and Medicine, Centre for Psychiatric Neurosciences, University of Lausanne, Prilly, Switzerland; <sup>e</sup>Agalma Foundation, Geneva, Switzerland

### ABSTRACT

In lateralized lexical decision tasks (LDTs), accuracy is higher and reaction times (RTs) are faster for right visual field (RVF) than left visual field (LVF) presentations. Visual field differences are thought to demonstrate the left hemisphere's (LH) dominance for language. The use of different tasks and words between studies and languages make direct comparisons difficult. We performed a lateralized LDT for which we selected four to six 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). *Lextale\_FR* a fast, free, and efficient test to measure language proficiency in French. *Psychologica Belgica*, 53(1), 23–27. Retrieved from <http://hdl.handle.net/1854/LU-4373981>]. Results showed a RVF over LVF advantage (accuracy, RTs and signal detection theory measures) for all groups, that is, 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 LH 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.

**ARTICLE HISTORY** Received 6 July 2015; Accepted 4 December 2015

**KEYWORDS** Lexical decision task; hemispheric lateralization; asymmetry; European languages; bilingual

Hemispheric specialization or “cerebral dominance” for a variety of cognitive functions has long been described from clinical observations on patients with

**CONTACT** Christine Mohr  [christine.mohr@unil.ch](mailto:christine.mohr@unil.ch)

© 2016 Taylor & Francis

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 (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 & Güntürkün, 2000; Mohr, Michel, et al., 2005), clinical relationships (Eyler, Pierce, & Courchesne, 2012; Grimshaw & Carmel, 2014; Mitchell & Crow, 2005) and individual difference relationships (Hausmann & Güntürkün, 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 specialization 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, 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 visual field (RVF) and left visual field (LVF). 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 (RTs)). 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 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 functional magnetic resonance imaging 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, non-words and their combinations) are often not published (e.g., Bryden & Rainey, 1963; Hausmann & Güntürkün, 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 and Switzerland). In such countries, bilingualism, if not multilingualism, is common often from an 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 and Italian) and two additional languages (English and Dutch). Participants were recruited in the French-speaking part of Switzerland. They had to make lexical decisions to four and six letter words and non-words 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 and languages spoken). In addition, we assessed participants' vocabulary knowledge with LEXTALE ([www.lextale.com](http://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 non-words. 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, that is, 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, that is, 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:  $((\text{sum of right hand crosses} - \text{sum of left hand crosses}) / \text{sum of all crosses}) * 100$ . 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  $-50$  and  $50$ ) and right-handers (LI's between  $50$  and  $100$ ).

## **Lateralized lexical decision task**

### **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 and 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, 3rd, or 4th quartile leaving us with 16 lowercased words: *agenda*, *alibi*, *aura*, *casino*, *film*, *gala*, *garage*, *jazz*, *jury*, *menu*, *radio*, *piano*, *snob*, *studio*, *taxi* and *virus* (see word frequencies in 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 (LDT), 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.

### *Non-word stimuli creation*

For each of the 16 words, we determined one non-word using the pseudo-word creator “Wuggy” (Keuleers & Brysbaert, 2010) (for the actual task material, see Appendix) to create word–non-word pairs. A priori, we selected non-words that differed from the corresponding word by two letters. Moreover, these non-words had to have relatively low values on the OLD20 scale and the Max Deviation Scale. By inference, each non-word had a relative dense neighbourhood of possible words (lower score on OLD20) and small differences between sub-syllabic segments in the word and non-word (lower score on Max Deviation) (Keuleers & Brysbaert, 2010). Finally, to create non-word–non-word pairs, we chose for each word the non-word listed second (based on above criteria) on the Wuggy-created non-word list. The other non-word for the non-word–non-word pair was the next non-word in the respective list for which two letters differed from the other non-word (Table A2). Thus, we applied analogue selection criteria for words and non-words, 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/non-word (16 pairs), non-word/word (16 pairs) and 32 non-word/non-word pairs (the 16 original non-word/non-word 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 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 non-word combinations can be found in Table A2. 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 RTs 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 1 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 non-word 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.<sup>1</sup>

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, that is, not taking only hit rate but also

---

<sup>1</sup>To note, among these 100 participants, 2 had reported cannabis use and 3 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.



false alarm rate into account. In particular, we determined the signal detection theory measures (i) *d*-prime (sensitivity) and (ii) 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 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 e.g., RVF: a non-word was shown to the RVF and the participant falsely gave a right response). Sensitivity was calculated separately for each visual field as *d*-prime =  $z(\% \text{ hit}) - z(\% \text{ false alarm})$ . Response biases were calculated separately for each visual field as *C*-biases =  $-1/2 * (z(\% \text{ hit}) + z(\% \text{ false alarm}))$ . The "z" indicates z-normalized data. Higher *d*-primes indicate better stimulus detection sensitivity, that is, 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.

Kolmogorov–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  $> .05$ ), apart from *C*-biases for the RVF ( $p = .20$ ). Also, age, handedness index scores 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 non-parametric comparisons.

For accuracy and RTs measures, we performed repeated measures analyses of variance (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  $\alpha$ -level was set at .05, unless otherwise stated. Effect sizes (partial eta-squared,  $\eta_p^2$ ) 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

**Table 1.** Means ( $\pm 1$  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.

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

Note: Values are provided for the total sample and the sexes separately.

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,  $\chi^2 = 0.003$ ,  $df = 1$ ,  $p = .953$ ), 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,  $\chi^2 = 1.609$ ,  $df = 2$ ,  $p = .447$ ) 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;  $\chi^2 = 0.363$ ,  $df = 1$ ,  $p = .547$ ).

### LDT lateralization

In average ( $\pm 1$  SD), across the 256 trials, participants indicated 58.34 times ( $\pm 18.10$ , range 14–99) that they saw a word on the left, 78.04 times ( $\pm 19.787$ , range 37–152) that they saw a word on the right, 107.41 times ( $\pm 29.749$ , range 19–171) that they saw no word on either side, and 12.45 times ( $\pm 14.711$ , range 1–80) 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  $p = .830$ ), C-biases tended to be higher in men than women (RVF:  $U = 776.00$ ,  $p = .075$ ; LVF:  $U = 785$ ,  $p = .087$ ) (Table 1).

### ***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:  $Z_H = 0.832$ ,  $p = .405$ ; RTs:  $Z_H = -0.319$ ,  $p = .750$ ;  $d$ -prime:  $Z_H = 1.415$ ,  $p = .157$ ; C-bias:  $Z_H = -0.690$ ,  $p = .490$ ).

### ***LDT lateralization and handedness***

We performed two sets of analyses, one on two handedness groups (left-handers and right-handers) and one on three handedness groups (left-handers, mixed-handers and 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, Kruskal–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),  $\chi^2 = 0.146$ ,  $p = .930$  for RVF presentations. For LVF presentations, Kruskal–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

**Table 2.** Means ( $\pm$  SD) for lateralized lexical decision task measures (accuracy, 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 ( $n = 19$ )
<i>Accuracy</i>					
RVF	47.73 $\pm$ 9.42	48.69 $\pm$ 9.35	48.02 $\pm$ 9.34	47.08 $\pm$ 9.28	49.16 $\pm$ 9.89
LVF	34.44 $\pm$ 11.62	34.38 $\pm$ 10.54	35.26 $\pm$ 11.79	29.92 $\pm$ 11.01	37.58 $\pm$ 8.42
<i>RT</i>					
RVF	760.77 $\pm$ 87.00	767.80 $\pm$ 125.57	762.18 $\pm$ 87.70	754.42 $\pm$ 87.54	775.30 $\pm$ 141.54
LVF	840.24 $\pm$ 119.76	849.35 $\pm$ 142.08	846.71 $\pm$ 123.64	843.51 $\pm$ 114.75	830.60 $\pm$ 150.63
<i>d-prime values</i>					
RVF	2.15 $\pm$ .57	2.27 $\pm$ .65	2.17 $\pm$ .59	2.10 $\pm$ .48	2.37 $\pm$ .71
LVF	1.52 $\pm$ .64	1.56 $\pm$ .60	1.56 $\pm$ .67	1.30 $\pm$ .54	1.75 $\pm$ .53
<i>C-bias values</i>					
RVF	0.27 $\pm$ .29	0.25 $\pm$ .31	0.27 $\pm$ .29	0.29 $\pm$ .27	0.24 $\pm$ .33
LVF	0.59 $\pm$ .30	0.61 $\pm$ .27	0.57 $\pm$ .30	0.69 $\pm$ .31	0.55 $\pm$ .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).

from each other (d-prime LVF:  $U = 508.00$ ,  $p = .688$ ; C-bias LVF:  $U = 531.00$ ,  $p = .900$ ).

### **LDT lateralization and multilingualism groups**

With regard to vocabulary knowledge, the early ( $71.61 \pm 5.59$ ) and late ( $71.05 \pm 10.07$ ) multilingual individuals did not differ in LEXTALE scores ( $U = 655.00$ ,  $p = .455$ ). For the two handedness groups, there was 1 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 3 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 and 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  $> .140$ ). 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 ( $\pm 1$  SD) for lateralized lexical decision task measures (accuracy, RTs, d-prime, C-bias) for LVF and RVF performance.

	Early ( $n = 18$ )		Late ( $n = 82$ )	
	RVF	LVF	RVF	LVF
Accuracy	$48.11 \pm 8.46$	$33.28 \pm 10.12$	$47.98 \pm 9.59$	$34.67 \pm 11.54$
RT	$763 \pm 76$	$871 \pm 135$	$763 \pm 104$	$837 \pm 124$
d-prime	$2.23 \pm .62$	$1.53 \pm .56$	$2.18 \pm .59$	$1.53 \pm .64$
C-bias	$0.28 \pm .27$	$0.63 \pm .29$	$0.26 \pm .30$	$0.59 \pm .29$

Note: 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).

## Discussion

The current study is the first to report data gathered in a lateralized LDT for an “international” vocabulary, that is, for words used in three of the four national languages spoken in Switzerland (French, German and 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 Christman, Henning, Geers, Propper, & Niebauer, 2008; Grimshaw, Yelle, Schoger, & Bright, 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 and 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](http://www.lextale.com)) (Lemhöfer & Broersma, 2012). Moreover, we found that enhanced LEXTALE scores related to better LVF performance (accuracy and RTs) in early bilinguals and to better RVF performance in late bilinguals (accuracy, RTs, d-prime and 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 non-words of four to six 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., 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, 2010; Hausmann, Hamm, Waldie, & Kirk, 2013).

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 occur 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 towards LVF performance in early multilingualism and towards 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 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, RTs and signal detection measures) gathered from a LDT using an “international” vocabulary (words existing in Dutch, English, French, German and 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).

## Acknowledgement

We would like to thank the Faculty of Social and Political Sciences, University of Lausanne, for supporting us with this first validation study.



## Disclosure statement

No potential conflict of interest was reported by the authors.

## References

- Allison, T., Puce, A., & McCarthy, G. (2000). Social perception from visual cues: Role of the STS region. *Trends in Cognitive Sciences*, 4(7), 267–278. doi:10.1016/S1364-6613(00)01501-1
- Arning, L., Ocklenburg, S., Schulz, S., Ness, V., Gerding, W. M., Hengstler, J. G., ... Beste, C. (2013). PCSK6 VNTR polymorphism is associated with degree of handedness but not direction of handedness. *PLoS One*, 8(6), e67251. doi:10.1371/journal.pone.0067251
- Baayen, R., Piepenbrock, R., & Gulikers, L. (1995). *CELEX2 LDC96L14*. Philadelphia, PA: Linguistic Data Consortium.
- Bayer, U., & Hausmann, M. (2009). Estrogen therapy affects right hemisphere functioning in postmenopausal women. *Hormones and Behavior*, 55(1), 228–234. doi:10.1016/j.yhbeh.2008.10.009
- Beaumont, J. G. (1982). Studies with verbal stimuli. In J. G. Beaumont (Ed.), *Divided visual field studies of cerebral organisation* (pp. 58–86). London: Academic Press.
- Bless, J. J., Westerhausen, R., von Koss Torkildsen, J., Gudmundsen, M., Kompus, K., & Hugdahl, K. (2015). Laterality across languages: Results from a global dichotic listening study using a smartphone application. *Laterality: Asymmetries of Body, Brain and Cognition*, 20(4), 434–452. doi:10.1080/1357650X.2014.997245
- Blumstein, S., Goodglass, H., & Tartter, V. (1975). The reliability of ear advantage in dichotic listening. *Brain and Language*, 2, 226–236. doi:10.1016/S0093-934X(75)80066-6
- Boles, D. B. (2002). Lateralized spatial processes and their lexical implications. *Neuropsychologia*, 40(12), 2125–2135. doi:10.1016/S0028-3932(02)00051-9
- Boles, D. B. (2005). A large-sample study of sex differences in functional cerebral lateralization. *Journal of Clinical and Experimental Neuropsychology*, 27(6), 759–768. doi:10.1081/13803390590954263
- Bourne, V. J. (2006). The divided visual field paradigm: Methodological considerations. *Laterality: Asymmetries of Body, Brain and Cognition*, 11(4), 373–393. doi:10.1080/13576500600633982
- Bradshaw, J. L. (1988). The evolution of human lateral asymmetries: New evidence and second thoughts. *Journal of Human Evolution*, 17(6), 615–637. doi:10.1016/0047-2484(88)90088-7
- Broca, P. (1865). Sur le siège de la faculté du langage articulé. *Bulletins de la Société d'anthropologie de Paris*, 6(1), 377–393. doi:10.3406/bmsap.1865.9495
- Bryden, M. P. (1965). Tachistoscopic recognition, handedness, and cerebral dominance. *Neuropsychologia*, 3(1), 1–8. doi:10.1016/0028-3932(65)90015-1
- Bryden, M. P. (1986). On the possible dangers of using horizontal word displays in visual field studies. *Brain and Cognition*, 5(3), 362–368. doi:10.1016/0278-2626(86)90037-0
- Bryden, M. P., & MacRae, L. (1988). Dichotic laterality effects obtained with emotional words. *Cognitive and Behavioral Neurology*, 1(3), 171–176.
- Bryden, M. P., & Rainey, C. A. (1963). Left-right differences in tachistoscopic recognition. *Journal of Experimental Psychology*, 66(6), 568–571. doi:10.1037/h0048905
- Brysbaert, M. (1994). Lateral preferences and visual field asymmetries: Appearances may have been overstated. *Cortex*, 30(3), 413–429. doi:10.1016/S0010-9452(13)80338-3

- Brynsbaert, M. (2013). Lextale\_FR a fast, free, and efficient test to measure language proficiency in French. *Psychologica Belgica*, 53(1), 23–27. Retrieved from <http://hdl.handle.net/1854/LU-4373981>
- Bulman-Fleming, M. B., & MacKinnon, G. E. (1998). Mark Philip Bryden: (November 14, 1934–August 18, 1996). *Brain and Cognition*, 36(2), 99–103. doi:10.1006/brcg.1997.0947
- Cabeza, R. (2002). Hemispheric asymmetry reduction in older adults: The HAROLD model. *Psychology and Aging*, 17(1), 85–100. doi:10.1037/0882-7974.17.1.85
- Carey, D. P., & Johnstone, L. T. (2014). Quantifying cerebral asymmetries for language in dextrals and adextrals with random-effects meta analysis. *Frontiers in Psychology*, 5, 1128. doi:10.3389/fpsyg.2014.01128
- Chee, M. W. L., Tan, E. W. L., & Thiel, T. (1999). Mandarin and English single word processing studied with functional magnetic resonance imaging. *Journal of Neuroscience*, 19(8), 3050–3056. doi:10.1523/JNEUROSCI.1930-99.2000
- Chiarello, C., Dronkers, N. F., & Hardyck, C. (1984). Choosing sides: On the variability of language lateralization in normal subjects. *Neuropsychologia*, 22(3), 363–373. doi:10.1016/0028-3932(84)90082-4
- Christman, S. D., Henning, B. R., Geers, A. L., Propper, R. E., & Niebauer, C. L. (2008). Mixed-handed persons are more easily persuaded and are more gullible: Interhemispheric interaction and belief updating. *Laterality: Asymmetries of Body, Brain and Cognition*, 13(5), 403–426. doi:10.1080/13576500802079646
- Cornelissen, P., Tarkiainen, A., Helenius, P., & Salmelin, R. (2003). Cortical effects of shifting letter position in letter strings of varying length. *Journal of Cognitive Neuroscience*, 15(5), 731–746. doi:10.1162/jocn.2003.15.5.731
- Cowell, P. E., Ledger, W. L., Wadnerkar, M. B., Skilling, F. M., & Whiteside, S. P. (2011). Hormones and dichotic listening: Evidence from the study of menstrual cycle effects. *Brain and Cognition*, 76(2), 256–262. doi:10.1016/j.bandc.2011.03.010
- Davis, C. J. (2005). N-Watch: A program for deriving neighbourhood size and other psycholinguistic statistics. *Behaviour Research Methods*, 37, 65–70.
- Efron, R. (1990). *The decline and fall of hemispheric specialization*. Hillsdale, NJ: Lawrence Erlbaum Associates.
- Eyler, L. T., Pierce, K., & Courchesne, E. (2012). A failure of left temporal cortex to specialize for language is an early emerging and fundamental property of autism. *Brain: A Journal of Neurology*, 135(3), 949–960. doi:10.1093/brain/awr364
- Fennell, E. (1977). Within-modal and cross-modal reliabilities of two laterality tests. *Brain and Language*, 4(1), 63–69. doi:10.1016/0093-934X(77)90006-2
- Forster, K. I., & Forster, J. C. (2003). DMDX: A windows display program with millisecond accuracy. *Behavior Research Methods, Instruments, & Computers*, 35(1), 116–124.
- Gardner, M. K., Rothkopf, E. Z., Lapan, R., & Lafferty, T. (1987). The word frequency effect in lexical decision: Finding a frequency-based component. *Memory & Cognition*, 15(1), 24–28. doi:10.3758/BF03197709
- Gazzaniga, M., Bogen, J., & Sperry, R. (1965). Observations on visual perception after disconnection of the cerebral hemispheres in man. *Brain: A Journal of Neurology*, 88(2), 221–236. doi:10.1093/brain/88.2.221
- Geffen, G., & Caudrey, D. (1981). Reliability and validity of the dichotic monitoring test for language laterality. *Neuropsychologia*, 19(3), 413–423. doi:10.1016/0028-3932(81)90071-3
- Gescheider, G. A. (1997). *Psychophysics: The fundamentals* (3rd ed.). Mahwah, NJ: Lawrence Erlbaum Associates.
- Green, D. E., & Swets, J. A. (1966). *Signal detection theory and psychophysics*. New York, NY: Wiley.

- Grimshaw, G. M., & Carmel, D. (2014). An asymmetric inhibition model of hemispheric differences in emotional processing. *Frontiers in Psychology, 5*, 489. doi:10.3389/fpsyg.2014.00489
- Grimshaw, G. M., Yelle, S. K., Schoger, J., & Bright, K. S. (2008). Magical ideation is related to questionnaire but not behavioural measures of handedness. *Laterality: Asymmetries of Body, Brain and Cognition, 13*(1), 22–33. doi:10.1080/13576500701508539
- Hausmann, M. (2010). Hormonal effects on the plasticity of cognitive brain functions. *Wiley Interdisciplinary Reviews: Cognitive Science, 1*(4), 607–612. doi:10.1002/wcs.21
- Hausmann, M., Behrendt-Körbitz, S., Kautz, H., Lamm, C., Radelt, F., & Güntürkün, O. (1998). Sex differences in oral asymmetries during word repetition. *Neuropsychologia, 36*(12), 1397–1402. doi:10.1016/S0028-3932(98)00027-X
- Hausmann, M., & Güntürkün, O. (1999). Sex differences in functional cerebral asymmetries in a repeated measures design. *Brain and Cognition, 41*(3), 263–275. doi:10.1006/brcg.1999.1126
- Hausmann, M., & Güntürkün, O. (2000). Steroid fluctuations modify functional cerebral asymmetries: The hypothesis of progesterone-mediated interhemispheric decoupling. *Neuropsychologia, 38*(10), 1362–1374. doi:10.1016/S0028-3932(00)00045-2
- Hausmann, M., Hamm, J. P., Waldie, K. E., & Kirk, I. J. (2013). Sex hormonal modulation of interhemispheric transfer time. *Neuropsychologia, 51*(9), 1734–1741. doi:10.1016/j.neuropsychologia.2013.05.017
- Hellige, J. B., Bloch, M. I., Cowin, E. L., Lee Eng, T., Eviatar, Z., & Sergent, V. (1994). Individual variation in hemispheric asymmetry: Multitask study of effects related to handedness and sex. *Journal of Experimental Psychology: General, 123*(3), 235–256. doi:10.1037/0096-3445.123.3.235
- Hirnstein, M., Westerhausen, R., Korsnes, M. S., & Hugdahl, K. (2013). Sex differences in language asymmetry are age-dependent and small: A large-scale, consonant-vowel dichotic listening study with behavioral and fMRI data. *Cortex, 49*(7), 1910–1921. doi:10.1016/j.cortex.2012.08.002
- Hiscock, M., Israelian, M., Inch, R., Jacek, C., & Hiscock-Kalil, C. (1995). Is there a sex difference in human laterality? II. An exhaustive survey of visual laterality studies from six neuropsychology journals. *Journal of Clinical and Experimental Neuropsychology, 17* (4), 590–610. doi:10.1080/01688639508405148
- Hoerger, M. (2013). *ZH: An updated version of Steiger's Z and web-based calculator for testing the statistical significance of the difference between dependent correlations*. Retrieved June 22, 2015 from [http://www.psychmike.com/dependent\\_correlations.php](http://www.psychmike.com/dependent_correlations.php)
- Hoff, H., & Pötzl, O. (1937). Über eine optisch-agnostische Störung des "Physiognomie-Gedächtnisses". *Zeitschrift für die gesamte Neurologie und Psychiatrie*.
- Howell, J. R., & Bryden, M. P. (1987). The effects of word orientation and imageability on visual half-field presentations with a lexical decision task. *Neuropsychologia, 25*(3), 527–538. doi:10.1016/0028-3932(87)90077-7
- Hugdahl, K. (2000). Lateralization of cognitive processes in the brain. *Acta Psychologica, 105*(2–3), 211–235. doi:10.1016/S0001-6918(00)00062-7
- Hugdahl, K. (2011). Fifty years of dichotic listening research—still going and going and . . . . *Brain and Cognition, 76*(2), 211–213. doi:10.1016/j.bandc.2011.03.006
- Hull, R., & Vaid, J. (2007). Bilingual language lateralization: A meta-analytic tale of two hemispheres. *Neuropsychologia, 45*(9), 1987–2008. doi:10.1016/j.neuropsychologia.2007.03.002

- Hunter, Z. R., & Brysbaert, M. (2008). Visual half-field experiments are a good measure of cerebral language dominance if used properly: Evidence from fMRI. *Neuropsychologia*, 46(1), 316–325. doi:10.1016/j.neuropsychologia.2007.07.007
- Ibrahim, R., & Eviatar, Z. (2012). The contribution of the two hemispheres to lexical decision in different languages. *Behavioral and Brain Functions*, 8, 3. doi:10.1186/1744-9081-8-3
- Jackson, J. H., & Gowers, W. R. (1875). *Case of large cerebral tumour without optic neuritis, and with left hemiplegia and imperception*. London: Harrison and Sons, printers.
- Keuleers, E., & Brysbaert, M. (2010). Wuggy: A multilingual pseudoword generator. *Behavior Research Methods*, 42(3), 627–633. doi:10.3758/BRM.42.3.627
- Kimura, D. (1961). Cerebral dominance and the perception of verbal stimuli. *Canadian Journal of Psychology*, 15(3), 166. doi:10.1037/h0083219
- Klein, D., Mok, K., Chen, J.-K., & Watkins, K. E. (2014). Age of language learning shapes brain structure: A cortical thickness study of bilingual and monolingual individuals. *Brain and Language*, 131, 20–24. doi:10.1016/j.bandl.2013.05.014
- Knecht, S., Dräger, B., Deppe, M., Bobe, L., Lohmann, H., Flöel, A., ... Henningsen, H. (2000). Handedness and hemispheric language dominance in healthy humans. *Brain: A Journal of Neurology*, 123(12), 2512–2518. doi:10.1093/brain/123.12.2512
- Lassonde, M., & Bryden, M. P. (1990). Dichotic listening, callosal agenesis and cerebral laterality. *Brain and Language*, 39(3), 475–481. doi:10.1016/0093-934X(90)90154-9
- Lassonde, M., Bryden, M. P., & Demers, P. (1990). The corpus callosum and cerebral speech lateralization. *Brain and Language*, 38(2), 195–206. doi:10.1016/0093-934X(90)90110-3
- Lemhöfer, K., & Broersma, M. (2012). Introducing LexTALE: A quick and valid lexical test for advanced learners of English. *Behavior Research Methods*, 44(2), 325–343. doi:10.3758/s13428-011-0146-0
- McGlone, J. (1980). Sex differences in human brain asymmetry: A critical survey. *Behavioral and Brain Sciences*, 3(2), 215–227. doi:10.1017/S0140525X00004398
- McKeever, W. F. (1971). Lateral word recognition: Effects of unilateral and bilateral presentation, asynchrony of bilateral presentation, and forced order of report. *The Quarterly Journal of Experimental Psychology*, 23(4), 410–416. doi:10.1080/14640747108400252
- McKeever, W. F., & VanDeventer, A. D. (1977). Visual and auditory language processing asymmetries: Influences of handedness, familial sinistrality, and sex. *Cortex*, 13(3), 225–241. doi:10.1016/S0010-9452(77)80033-6
- McManus, I. C., Corballis, M. C., & Bulman-Fleming, M. B. (1996). Philip Bryden: November 14, 1934 ± August 18, 1996. *Laterality: Asymmetries of Body, Brain and Cognition*, 1, 257–268. doi:10.1080/713754244
- McMullen, P., & Bryden, M. P. (1987). The effects of word imageability and frequency on hemispheric asymmetry in lexical decisions. *Brain and Language*, 31(1), 11–25. doi:10.1016/0093-934X(87)90057-5
- Mikheev, M., Mohr, C., Afanasiev, S., Landis, T., & Thut, G. (2002). Motor control and cerebral hemispheric specialization in highly qualified judo wrestlers. *Neuropsychologia*, 40(8), 1209–1219. doi:10.1016/S0028-3932(01)00227-5
- Mitchell, R. L., & Crow, T. J. (2005). Right hemisphere language functions and schizophrenia: The forgotten hemisphere? *Brain: A Journal of Neurology*, 128(5), 963–978. doi:10.1093/brain/awh466
- Mohr, C., Krummenacher, P., Landis, T., Sandor, P. S., Fathi, M., & Brugger, P. (2005). Psychometric schizotypy modulates levodopa effects on lateralized lexical decision performance. *Journal of Psychiatric Research*, 39(3), 241–250. doi:10.1016/j.jpsychires.2004.08.006

- Mohr, C., Michel, C. M., Lantz, G., Ortigue, S., Viaud-Delmon, L., Landis, T., & Viaud-Delmon, I. (2005). Brain state-dependent functional hemispheric specialization in men but not in women. *Cerebral Cortex*, *15*(9), 1451–1458. doi:10.1093/cercor/bhi025
- New, B., Pallier, C., Brysbaert, M., & Ferrand, L. (2004). Lexique 2: A new French lexical database. *Behavior Research Methods, Instruments, & Computers*, *36*(3), 516–524. doi:10.3758/BF03195598
- Nicholls, M. E., Orr, C. A., & Lindell, A. K. (2005). Magical ideation and its relation to lateral preference. *Laterality: Asymmetries of Body, Brain and Cognition*, *10*(6), 503–515. doi:10.1080/13576500442000265
- Nicholls, M. E. R., Thomas, N. A., Loetscher, T., & Grimshaw, G. M. (2013). The Flinders Handedness survey (FLANDERS): A brief measure of skilled hand preference. *Cortex*, *49*(10), 2914–2926. doi:10.1016/j.cortex.2013.02.002
- Ocklenburg, S., Beste, C., Arning, L., Peterburs, J., & Güntürkün, O. (2014). The ontogenesis of language lateralization and its relation to handedness. *Neuroscience and Biobehavioral Reviews*, *43*, 191–198. doi:10.1016/j.neubiorev.2014.04.008
- Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia*, *9*(1), 97–113. doi:10.1016/0028-3932(71)90067-4
- Orenstein, H. B. (1976). A reply to McKeever's 'On Orenstein's and Meighan's finding of left visual field recognition superiority for bilaterally presented words'. *Bulletin of the Psychonomic Society*, *8*(2), 87. doi:10.3758/BF03335088
- Ortigue, S., Thut, G., Landis, T., & Michel, C. M. (2005). Time-resolved sex differences in language lateralization. *Brain: A Journal of Neurology*, *128*(5), E28, author reply E29. doi:10.1093/brain/awh386
- Paradis, M. (2008). Bilingual laterality: Unfounded claim of validity: A comment on Hull and Vaid (2007). *Neuropsychologia*, *46*(5), 1588–1590. doi:10.1016/j.neuropsychologia.2008.01.029
- Ratcliff, R., Gomez, P., & McKoon, G. (2004). A diffusion model account of the lexical decision task. *Psychological Review*, *111*(1), 159–182. doi:10.1037/0033-295X.111.1.159
- Scott, G. B., & Hellige, J. B. (1998). Hemispheric asymmetry for word naming: Effects of frequency and regularity of pronunciation. *Laterality: Asymmetries of Body, Brain and Cognition*, *3*(4), 343–371. doi:10.1080/713754310
- Shaywitz, B. A., Shaywitz, S. E., Pugh, K. R., Constable, R. T., Skudlarski, P., Fulbright, R. K., ... Gore, J. C. (1995). Sex differences in the functional organization of the brain for language. *Nature*, *373*(6515), 607–609. doi:10.1038/373607a0
- Sommer, I. E., Aleman, A., Somers, M., Boks, M. P., & Kahn, R. S. (2008). Sex differences in handedness, asymmetry of the planum temporale and functional language lateralization. *Brain Research*, *1206*, 76–88. doi:10.1016/j.brainres.2008.01.003
- Sperry, R. (1982). Some effects of disconnecting the cerebral hemispheres. *Bioscience Reports*, *2*(5), 265–276. doi:10.1007/BF01115112
- Teng, E. L. (1981). Dichotic ear difference is a poor index for the functional asymmetry between the cerebral hemispheres. *Neuropsychologia*, *19*(2), 235–240. doi:10.1016/0028-3932(81)90107-X
- Thilers, P. P., MacDonald, S. W. S., & Herlitz, A. (2007). Sex differences in cognition: The role of handedness. *Physiology & Behavior*, *92*(1–2), 105–109. doi:10.1016/j.physbeh.2007.05.035
- Van der Haegen, L., Cai, Q., Seurinck, R., & Brysbaert, M. (2011). Further fMRI validation of the visual half field technique as an indicator of language laterality: A large-group analysis. *Neuropsychologia*, *49*(10), 2879–2888. doi:10.1016/j.neuropsychologia.2011.06.014

- Van der Haegen, L., Westerhausen, R., Hugdahl, K., & Brysbaert, M. (2013). Speech dominance is a better predictor of functional brain asymmetry than handedness: A combined fMRI word generation and behavioral dichotic listening study. *Neuropsychologia*, 51(1), 91–97. doi:10.1016/j.neuropsychologia.2012.11.002
- Voyer, D. (1998). On the reliability and validity of noninvasive laterality measures. *Brain and Cognition*, 36(2), 209–236. doi:10.1006/brcg.1997.0953
- Voyer, D. (2003). Reliability and magnitude of perceptual asymmetries in a dichotic word recognition task. *Neuropsychology*, 17(3), 393–401. doi:10.1037/0894-4105.17.3.393
- Voyer, D. (2011). Sex differences in dichotic listening. *Brain and Cognition*, 76(2), 245–255. doi:10.1016/j.bandc.2011.02.001
- Weems, S. A., & Reggia, J. A. (2004). Hemispheric specialization and independence for word recognition: A comparison of three computational models. *Brain and Language*, 89(3), 554–568. doi:10.1016/j.bandl.2004.02.001
- Wernicke, C. (1874). *Der aphasische Symptomencomplex: Eine psychologische Studie auf anatomischer Basis*. Breslau: Max Cohn & Weigert.
- Westerhausen, R., Bless, J. J., Passow, S., Kompus, K., & Hugdahl, K. (2015). Cognitive control of speech perception across the lifespan: A large-scale cross-sectional dichotic listening study. *Developmental Psychology*, 51(6), 806–815. doi:10.1037/dev0000014
- World Medical Association. (2001). World medical association declaration of Helsinki. Ethical principles for medical research involving human subjects. *Bulletin of the World Health Organization*, 79(4), 373–374.

## Appendix

**Table A1.** List of the 16 words and their respective word frequencies in English and French.

Word	Word frequency	
	English (CELEX)	French (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 non-word stimuli as presented in pairs in the lateralized lexical decision task.

Stimuli 1	Stimuli 2
<b>agenda</b>	asenga
<b>alibi</b>	acipi
<b>aura</b>	aita
<b>casino</b>	caniso
<b>film</b>	fitz
<b>gala</b>	dara
<b>garage</b>	lapage
<b>jazz</b>	jaik
<b>jury</b>	jula
<b>menu</b>	besu
<b>piano</b>	pieni
<b>radio</b>	rapoo
<b>snob</b>	ssib
<b>studio</b>	slugio
<b>taxi</b>	taia
<b>virus</b>	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

Notes: Each pair would be shown in above sequence, but also in the reversed order. The bold stimuli are meaningful words in French, English, German, Italian and Dutch.

Copyright of Laterality is the property of Taylor & Francis Ltd and its content may not be copied or emailed to multiple sites or posted to a listserv without the copyright holder's express written permission. However, users may print, download, or email articles for individual use.