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Identifying cortical first and second language sites via navigated transcranial magnetic stimulation of the left hemisphere in bilinguals

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The cortical areas that code for the first (L1) and second language (L2) in bilinguals have still not been sufficiently explored. Thus, this study investigated the left-hemispheric distribution of the L1 and L2 using repetitive navigated transcranial magnetic stimulation (rTMS), in combination with an object-naming task, in 10 healthy, right-handed volunteers.

In particular, higher error rates (ERs) were observed in the L1, and there was a statistically significant difference between the ERs of L1 and L2 for no-response errors (L1 mean 11.9 ± 9.0%, L2 mean 6.5 ± 5.2%; p = 0.03). Furthermore, language-specific and shared cortical distribution patterns for the L1 and L2 were observed within the frontal, parietal, and temporal lobes with a trend towards higher occurrence of language-specific spots within posterior regions. Overall, the L1 presented a more stable pattern of language distribution compared to the L2.

1. Introduction

Currently, no universal definition of bilingualism is available (Blom, Kuntay, Messer, Verhagen, & Leseman, 2014). In this study, we adopted the definition given by Kohnert (2010), according to which bilinguals are "individuals who receive regular input in two…languages during the most dynamic period of communication development—somewhere between birth and adolescence" (Kohnert, 2010). A variety of studies have investigated which brain structures are required for first (L1) and second language (L2) processing in bilinguals; however, no clear results on which cortical areas are involved have been obtained yet. The majority of neuroimaging and intraoperative stimulation research suggests that, in addition to common brain areas that code for both L1 and L2 processing, some cortical regions are specific to either L1 or L2 processing (Calabrese et al., 2001; Chee, Hon, Lee, & Soon, 2001; Chee, Tan, & Thiel, 1999; Dehaene et al., 1997; Illes et al., 1999; Lucas, McKhann, & Ojemann, 2004; Pouratian et al., 2000; Roux & Tremoulet, 2002). For example, Lucas et al. (2004), who performed intraoperative stimulation in 25 bilingual patients and 117 monolingual control patients, reported on language-specific sites in the inferior frontal area and posterior inferior parietal area (Lucas et al., 2004). Comparable to these findings, Roux and Tremoulet (2002) were also able to map language-specific sites within frontal and temporo-parietal areas intraoperatively (Roux & Tremoulet, 2002). Furthermore, a case report using intraoperative optical imaging reported on language-specific sites within the supramarginal and precentral gyrus (Pouratian et al., 2000). Regarding studies using functional magnetic resonance imaging (fMRI), Chee et al. found increased activation in opercular regions for L2 (Chee et al., 2001), whereas Dehaene et al. showed that areas coding for L1 were primarily located in the left temporal lobe with L2-specific areas being highly variable within temporal and frontal areas (Dehaene et al., 1997). However, not all studies or paradigms of investigation have been able to resolve spatial separations between L1 and L2 (Chee et al., 1999; Illes et al., 1999).

Abbreviations: CPS, Cortical Parcellation System; DTI FT, diffusion tensor imaging fiber tracking; DT, display time; EHI, Edinburgh Handedness Inventory; ER, error rate; fMRI, functional magnetic resonance imaging; IPI, inter-picture interval; L1, first language; L2, second language; LH, left hemisphere; MRI, magnetic resonance imaging; PTI, picture-to-trigger interval; RMT, resting motor threshold; rTMS, repetitive navigated transcranial magnetic stimulation; VAS, Visual Analogue Scale.

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Taking these findings together, it seems that the two languages in bilinguals are at least partially processed by different cortical areas. However, it is still difficult to draw definite conclusions from the research that has been conducted, as the results are derived from various studies in which the subjects differ in their age of L2 acquisition, their proficiency, and the context of the language acquisition, which are all factors that seem to impact the extent of the cortical overlap of the L1 and L2 (Blom et al., 2014). Furthermore, the tasks that the enrolled subjects had to perform in the studies varied, including phonological, word fluency, cue-word generation, working memory, and object-naming tasks. Because different tasks probably involve different brain regions (Buckner, Raichle, & Petersen, 1995), it is difficult to have a clear understanding of which functions are solved by different regions in bilinguals. Moreover, most of the studies conducted on bilingualism have used neuroimaging techniques, which, despite providing valuable insights, do not directly reveal a causal link between the regional activations observed and the functional processes involved. Thus, this study uses left-hemispheric repetitive navigated transcranial magnetic stimulation (rTMS) during an object-naming paradigm to specifically explore potential differences between task performance in L1 and L2 among healthy bilinguals within the scope of two hypotheses: (1) The L1 and L2 show different cortical distributions in the left hemisphere (LH), and (2) while the L1 shows a similar and stable pattern in all volunteers, the L2 shows a more varying pattern compared to the L1.

2. Material and methods

2.1. Study design

The study was prospective and non-randomized.

2.2. Ethics approval statement

This study was carried out in accordance with the recommendations of our local ethics committee (registration number: 2793/10). All of the subjects gave written informed consent in accordance with the Declaration of Helsinki.

2.3. Participants

Ten healthy bilingual volunteers (7 females and 3 males, median age 23 years) took part in the study. The participants had to meet the Kohnert (2010) definition of bilingualism (Kohnert, 2010), as stated initially. As such, the participants were required to have acquired their L2 before the age of 10 years according to self-report. To check for comparable proficiency in L1 and L2 regarding the objects shown during the naming task, all volunteers underwent baseline testing without stimulation twice before rTMS-based mapping, but no other assessment of proficiency concerning bilingualism was carried out.

Other inclusion criteria were age above 18 years, right-handedness according to the Edinburgh Handedness Inventory (EHI), and a written consent form. The exclusion criteria were left-handedness, less or more than two languages acquired before the age of 10 years, previous seizures, general rTMS exclusion criteria (e.g., pacemaker, cochlear implant, deep brain stimulation electrodes), and pathological findings on cranial imaging. Furthermore, volunteers that showed a difference of more than 13 correctly named objects (10% of the overall amount of presented objects) between L1 and L2 during baseline testing were excluded.

2.4. Magnetic resonance imaging

All of the subjects underwent magnetic resonance imaging (MRI) before rTMS mapping. Scanning was conducted using a 3 T MRI scanner (Achieva 3 T, Philips Medical Systems, The Netherlands B.V.), in combination with an 8-channel phased-array head coil. A three-dimensional gradient echo sequence (TR/TE 9/4 ms, 1 mm^3 isovoxel covering the whole head, 6 min and 58 s acquisition time) was acquired without intravenous contrast agent.

2.5. Language mapping

The subjects' LH was mapped twice, 14 days apart, in randomized order regarding the L1 and L2. The procedures for both mappings were the same. First, the three-dimensional MRI data of each subject were co-registered to the volunteer's cranium, in order to provide a navigational template for rTMS mapping, which was conducted with the Nexstim eXimia NBS system (version 4.3) with a NexSpeech® module (Nexstim Plc., Helsinki, Finland). The system tracks the coil's position with respect to the head using a stereotactic camera, which senses both the coil and the reflectors positioned on a strap tied to the subject's head. The locations of the induced field and stimulation spots were displayed on the MRI data and recorded for further analysis (Ilmoniemi, Ruohonen, & Karhu, 1999; Krieg et al., 2016; Ruohonen & Karhu, 2010; Sollmann et al., 2014).

Prior to language mapping, the optimal stimulation intensity for each volunteer was established by determining the resting motor threshold (RMT), which was obtained by stimulating the cortical representation of the contralateral abductor pollicis brevis muscle with decreasing intensities, following previously described protocols (Krieg et al., 2012; Picht et al., 2009, 2012). During language mapping, the subjects performed an object-naming task consisting of 131 colored photographs of everyday objects (Krieg et al., 2016; Picht et al., 2013; Sollmann et al., 2014), which appeared on a screen that was located approximately 60 cm in front of the volunteer. A video camera with a built-in microphone recorded the task performance of each individual during baseline testing and rTMS mapping (Hernandez-Pavon, Makela, Lehtinen, Lioumis, & Makela, 2014; Krieg et al., 2016; Lioumis et al., 2012; Picht et al., 2013; Sollmann et al., 2014). Recording was started immediately before the presentation of the first object on the screen, and it lasted until screening of the last object, shown during application of the final stimulation burst according to our stimulation protocol, was finished.

During mapping, the inter-picture interval (IPI) was 2500 ms, the display time (DT) of each object was 700 ms, and the train of the stimuli was delivered simultaneously with picture presentation in a time-locked fashion, with a picture-to-trigger interval (PTI) of 0 ms (Krieg et al., 2014). The stimulation was performed with 100% RMT at a frequency of 5 Hz/5 pulses, with the coil oriented anterior-posteriorly, as published earlier (Krieg et al., 2016; Rosler et al., 2014; Sollmann et al., 2014; Tarapore et al., 2013). This protocol has demonstrated to be easily tolerable and efficient in terms of elicitation of naming errors during rTMS-based language mapping, and can currently be regarded as the most common approach (Krieg et al., 2016; Rosler et al., 2014; Sollmann et al., 2014; Tarapore et al., 2013).

The subjects were asked to name clearly and as quickly as possible each of the 131 objects that appeared sequentially on the screen (Krieg et al., 2016; Picht et al., 2013; Sollmann et al., 2014). The task was repeated twice without stimulation to establish a baseline, from which all objects that did not elicit clear or correct responses were excluded. The baseline objects were then utilized under rTMS for the mapping phase (Krieg et al., 2016; Picht et al., 2013; Sollmann et al., 2014).