The Influence of the Laboratory Environment on the Measurement of Language Lateralisation

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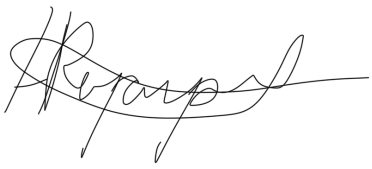
Declaration

I declare that this thesis is entirely my own work except where I have given full documented references to the work of others. The material contained in this thesis has not been submitted for a higher degree to any other university or institution. This project was approved by the Human Research Ethics Committee of Macquarie University (Reference No: 5201500074).



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Abstract

Hemispheric lateralisation can be assessed with both functional magnetic resonance imaging (fMRI) and functional transcranial Doppler ultrasonography (fTCD). However, concordance between these techniques is imperfect. This discrepancy may be partially explained by differences in the fMRI and fTCD laboratory environments: while fMRI occurs in a noisy, confined space in which subjects lie supine, fTCD typically occurs in a quiet, unconfined space in which subjects sit upright. This study investigated the influence of the fMRI and fTCD laboratory environments on the measurement of language lateralisation. Across two experiments, fTCD was used to measure the consistency of language lateralisation while participants performed a word generation task either twice in an fTCD environment (control condition), or once in an fTCD environment and then in a simulated fMRI environment (experimental condition). Relative to the control condition, test-retest reliability of lateralisation estimates was considerably poorer in the experimental condition. Consistent with this, several participants in the experimental condition switched lateralisation categories between the two testing sessions. These findings suggest that the laboratory environment may partially account for the discordance between fMRI and fTCD lateralisation estimates. Future research should embrace protocols that aim to reduce the interference of the laboratory environment, such as noise-cancelling headphones and open, multi-postural fMRI, to further our understanding of hemispheric lateralisation.

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The Influence of the Laboratory Environment on the Measurement of Language Lateralisation

Hemispheric lateralisation is the extent to which some cognitive functions, such as language and spatial attention, are more dominant in one cerebral hemisphere over the other. Hemispheric lateralisation can be assessed non-invasively with both functional magnetic resonance imaging (fMRI) and functional transcranial Doppler ultrasonography (fTCD). However, concordance between these techniques is imperfect. This discrepancy may be partially explained by differences in the fMRI and fTCD laboratory environments: while fMRI occurs in a noisy, confined space in which participants lie supine, fTCD typically occurs in a quiet, unconfined space in which participants sit upright. In this thesis, I investigated the influence of the fMRI and fTCD laboratory environments, which differ in terms of noise, space and posture, on the measurement of hemispheric language lateralisation.

Hemispheric Lateralisation

The human brain is composed of two cerebral hemispheres, separated by a deep groove called the longitudinal fissure and connected by an extensive network of fibres called the corpus callosum. Complex cognitive functions, such as language and spatial attention, utilise the uppermost mantel of the brain – the cerebral cortex. The phenomenon by which some cognitive functions are mediated by one cerebral hemisphere more than the other is known as hemispheric lateralisation. In most people, language is left lateralised and spatial attention is right lateralised. The functional relevance of hemispheric lateralisation is poorly understood, although it has been suggested that a lateralised brain may process information more efficiently, reflecting an evolutionary advantage (Cai, Van der Haegen, & Brysbaert, 2013). Indeed, disruptions to the development of typical left language lateralisation have been associated with a range of neurodevelopmental and psychiatric disorders, including dyslexia (Illingworth & Bishop, 2009), specific language impairment (Whitehouse & Bishop, 2008),

autism (Preslar, Kushner, Marino, & Pearce, 2014), attention deficit hyperactivity disorder (Sigi Hale, Bookheimer, McGough, Phillips, & McCracken, 2007) and schizophrenia (Bertolino et al., 2004). However, typical lateralisation does not appear to provide a cognitive advantage in typically developing individuals. A study of healthy participants with left (n = 264), bilateral (n = 31) and right (n = 31) language lateralisation found no relationship between language lateralisation (degree and direction) and mastery of foreign languages, academic achievement, artistic talent, verbal fluency, intelligence or speed of linguistic processing (Knecht et al., 2001). The functional relevance of hemispheric lateralisation therefore remains unclear.

Methods Used to Assess Hemispheric Lateralisation

Today, hemispheric lateralisation (hereafter, lateralisation) is assessed using the pre-surgical Wada test, various behavioural measures and functional brain imaging. Prior to the development of these modern techniques, investigations of lateralisation came primarily from post-mortem lesion studies.

Post-mortem lesion studies.

The first systematic investigation of lateralisation is generally credited to French neurologist, Paul Broca (1865), who famously postulated that *"Nous parlons avec l'hémisphère gauche"* (*"We speak with the left hemisphere"*). This finding was based on post-mortem lesion studies in which Broca found damage to the left frontal lobe in patients who had had impaired language production. Several years later, German physician, Carl Wernicke (1874), observed damage to the left temporoparietal cortex in patients who had had impaired language comprehension despite fluent word production. These regions are now referred to as Broca's area and Wernicke's area, respectively. The discovery of functional differences between the two hemispheres has since been validated with the Wada test, behavioural measures and functional brain imaging.

The Wada test.

The gold standard method for assessing lateralisation is the intracarotid amobarbital procedure (also known as the Wada test; Wada, 1949). The procedure involves temporarily disrupting the function of one brain hemisphere by injecting a barbiturate into the ipsilateral carotid artery. While one hemisphere is anesthetized, the individual performs a series of language and spatial attention tasks, and then the procedure is repeated for the other hemisphere. The direction of lateralisation for language and spatial attention is determined by which hemisphere is associated with best performance. The Wada test is essential preparation for resective neurosurgery for epilepsy patients to determine the risk of cognitive impairment following the removal of brain tissue (Deppe et al., 2000). This practice has significantly improved post-surgery cognitive outcomes (Lezak, 2004). The Wada test is also used to obtain a baseline measure for monitoring cognitive restoration following stroke (Deppe et al., 2000). However, the Wada test is highly invasive and carries a small but definite risk of fatality (Kekhia, Rigolo, Norton, & Golby, 2011). It is therefore used exclusively for medical purposes and is not viable in studies with non-patient populations.

Behavioural measures.

Behavioural measures, such as handedness, the visual half field paradigm and the dichotic listening paradigm, have been used extensively as a non-invasive alternative to the Wada test for assessing lateralisation (Pelletier, Sauerwein, Lepore, Saint-Amour, & Lassonde, 2007). These techniques are portable, inexpensive, and can be administered with both children and adults.

Handedness.

Handedness has historically been used as a proxy measure of lateralisation. In the 1860s, Paul Broca speculated that a person's hand preference was opposite to the side of the brain lateralised for language, such that right-handers are left lateralised for language and

left-handers are right lateralised for language. However, recent research has challenged this notion, finding that, although significant, the association between language lateralisation and handedness is imperfect (Groen, Whitehouse, Badcock, & Bishop, 2013). While 90% of right-handers are left lateralised for language, 67-85% of left-handers are also left lateralised for language. Therefore, handedness provides only a rough indication of language lateralisation.

Dichotic listening and visual half field tests.

Two additional behavioural measures for assessing lateralisation are the dichotic listening test (Kimura, 1967) and the visual half field test (Hunter & Brysbaert, 2008). Both are based on the idea that a stimulus presented to one side of the body is initially processed by the contralateral hemisphere due to contralateral neural wiring. During the dichotic listening test, participants are presented with competing auditory stimuli to the two ears. Participants are then required to report as much as possible about both stimuli. Most people show a right ear advantage for verbal stimuli (indicating left lateralisation) and a left ear advantage for non-verbal stimuli (indicating right lateralisation). An equivalent finding has been demonstrated for visual stimuli. During the visual half field test, participants are asked to fixate on a central point and visual stimuli are presented in either the left- or right-half of the visual field. Most people show a right visual field advantage for verbal stimuli (indicating left lateralisation) and a left visual field advantage for non-verbal stimuli (indicating right lateralisation). Both dichotic listening (Hund-Georgiadis, Lex, Friederici, & von Cramon, 2002) and the visual half field (Hunter & Brysbaert, 2008) tests have shown high concordance with functional magnetic resonance imaging for assessing lateralisation. However, these techniques are less accurate when detecting bilateral activation (Pelletier et al., 2007). Recent advances in brain imaging techniques offer an alternative method for the non-invasive assessment of lateralisation.

Functional brain imaging.

Most non-invasive brain imaging techniques used to assess lateralisation are based on the blood flow response to cerebral activation (Abou-Khalil, 2007). These techniques capitalise on the close coupling between changes in regional neural activity and changes in its blood supply, such that increases in neural activity lead to an increase in blood supply (Rosengarten, Osthaus, & Kaps, 2002). Functional magnetic resonance imaging (fMRI) and functional transcranial Doppler ultrasonography (fTCD) are two techniques based on the blood flow response that have been validated against the Wada test for determining language lateralisation (fMRI: r =.96; Binder et al., 1996; fTCD: r = .92; Knecht, Deppe, Ebner, et al., 1998). A lateralisation index (LI) is calculated based on a comparison of task-related blood flow in each hemisphere. Positive LIs indicate left lateralisation and negative LIs indicate right lateralisation.

Functional magnetic resonance imaging.

FMRI based on the blood oxygenation level-dependent (BOLD) signal (Ogawa, Lee, Nayak, & Glynn, 1990) has received the most attention as a replacement for the Wada test for determining lateralisation (Abou-Khalil, 2007). The BOLD signal relies on the fact that oxygen flows to activated brain regions in excess of the amount required (Gallagher & Nelson, 2003). As such, the oxygen content of the blood is higher when it leaves the active region compared to a less active region. Continuous changes in the ratio of oxygenated to deoxygenated blood during a cognitive task indicate changes in neural activity in the region of interest. FMRI has risen in popularity, due in part to its excellent spatial resolution, as well as its wide availability (Abou-Khalil, 2007). However, fMRI suffers from artefacts due to movement and is therefore limited to individuals who are able to lie still for a long period of time inside the narrow scanner bore and cooperate sufficiently with a cognitive task. As such, it is less suitable for young children and psychiatric populations, or individuals who suffer

from claustrophobia (Raz et al., 2005). Even small head movements that occur during speech can degrade the quality of the images. This has restricted fMRI research on speech production and the ability to include verbal responses in cognitive tasks. FMRI also precludes individuals who are excessively obese due to restricted space, as well as individuals who have pacemakers or other metal implants or prostheses due to the risk of severe complications and even death caused by interactions between the magnetic objects and the fMRI magnetic surrounds.

Functional transcranial Doppler ultrasonography.

FTCD presents as a viable alternative to fMRI for the non-invasive determination of lateralisation (Knecht, Deppe, Ebner, et al., 1998). During fTCD assessment, low frequency (1-2 MHz) ultrasound probes are positioned over the temporal bone window (the thinnest portion of the temporal bone) to allow the ultrasonic beam to penetrate the skull and insonate the middle, anterior, or posterior cerebral arteries (Aaslid, Markwalder, & Nornes, 1982). To measure cerebral blood flow velocity (CBFV) through the cerebral arteries, fTCD utilises the Doppler effect by comparing frequency changes of the transmitted and returned ultrasound signals reflected by the moving blood cells within the artery (Badcock & Groen, 2017). Lateralisation is determined by which hemisphere has greater task-related CBFV. The left and right middle cerebral arteries are the most commonly insonated vessels in lateralisation research as they supply blood to approximately 50% of the cerebral cortex, including brain regions responsible for language function (e.g., Broca's and Wernicke's areas; van der Zwan, Hillen, Tulleken, & Dujovny, 1993). Unlike fMRI, fTCD is inexpensive, portable, easily applied and unaffected by small movements. Furthermore, there is no physical space confinement involved in fTCD assessment. As such, it is viable for testing large cohorts, including individuals for whom fMRI is unsuitable, including young children, psychiatric populations, as well as individuals who are obese, have metal implants or suffer from

claustrophobia. While fTCD has high temporal resolution, its spatial resolution is restricted to the cortex supplied by the insonated blood vessels and, with respect to lateralisation, it cannot provide localised information beyond comparing the CBFV through the cerebral arteries. Furthermore, approximately 5% of subjects lack an acoustic temporal bone window and cannot be assessed (Deppe et al., 2000).

Experimental tasks for assessing hemispheric lateralisation.

Studies comparing lateralisation estimates between fMRI and fTCD typically use the Word Generation task (Knecht et al., 1996) to assess language lateralisation, and the Landmark task (Flöel et al., 2002) to assess spatial attention lateralisation.

The Word Generation task.

The Word Generation (WG) task is the gold-standard paradigm for determining language lateralisation with fTCD. Five seconds after a cueing tone, participants have 15 seconds to silently generate as many words as possible starting with a letter displayed on a screen. Subsequently, task compliance is confirmed by asking participants to say aloud the words they silently generated within a 5-second period. Finally, the message “relax” appears on the screen, marking the beginning of a 35-second relaxation period to allow CBFV to return to resting state. The relaxation period also serves as a baseline against which silent word generation activation can be compared. Each trial lasts for 60 seconds and the task typically consists of 23 trials: one trial for each letter of the alphabet, excluding letters that are infrequently used in the given language (e.g., Q, X, Z in English studies). The task, first introduced by Knecht et al. (1996) is reliable (Knecht, Deppe, Ringelstein, et al., 1998) and has been validated against the Wada test (Knecht, Deppe, Ebner, et al., 1998) and fMRI (Deppe et al., 2000; Somers et al., 2011).

The Landmark task.

While the WG task has been considered the gold standard language lateralisation paradigm for two decades, consensus on a comparable paradigm for assessing spatial attention lateralisation has yet to be achieved (Whitehouse, Badcock, Groen, & Bishop, 2009). The Landmark task is the most commonly used paradigm for assessing spatial attention lateralisation. Five seconds after a cueing tone, participants have 10 seconds to silently decide whether a horizontal line is bisected by a vertical line in the exact centre, or slightly deviating to the left or right. Subsequently, task compliance is confirmed by asking participants to report their decision (e.g., with a button press) within a 5-second period. Finally, an auditory signal marks the beginning of a 20-second relaxation period to allow CBFV to return to a resting state and to obtain a baseline estimate. Each trial lasts for 40 seconds and the task usually consists of 20 trials, where the vertical line appears four times in five different locations on the screen in a randomised order (Flöel et al., 2002).

Concordance Between FMRI and FTCD

As neuroscience moves towards comparing data across multiple imaging modalities, the question arises as to how well fMRI and fTCD agree in the assessment of lateralisation. To address this question, I performed a PubMed search with the keywords “fMRI” and “fTCD”. This yielded 24 articles. Of these, five investigated the agreement between fMRI and fTCD in assessing lateralisation in groups of healthy adults (Deppe et al., 2000; Hattemer et al., 2011; Jansen et al., 2004; Schmidt et al., 1999; Somers et al., 2011). Additionally, an unpublished Oxford University Doctor of Philosophy thesis (Bruckert, 2016) also matched the search criteria. Correlations between the fMRI and fTCD reported in these studies are presented in Table 1. Note that rule of thumb for interpreting the correlations in the following section comes from Hinkle et al. (2003).

Table 1

Correlation Between FMRI and FTCD Lateralisation Estimates in Previous Studies

Citation	Cognitive Function	Task	Correlation	
Deppe et al., 2000	Language	Word Generation	Pearson's *r*	.95
Somers et al., 2011	Language	Word Generation	Spearman's *rho*	.75
Bruckert, 2016	Language	1. Auditory Naming	Spearman's *rho*	.59
	Language	2. Word Generation	Spearman's *rho*	.49
	Language	3. Semantic Matching	Spearman's *rho*	.44
Jansen et al., 2004[1]	Spatial Attention	Landmark	Pearson's *r*	.69
Schmidt et al., 1999	Spatial Attention	Spot the Difference	Spearman's *rho*	.54
Hattemer et al. 2011	Spatial Attention	Mental Rotation	Pearson's *r*	.34

To date, three studies have investigated the agreement between fMRI and fTCD in the assessment of language lateralisation. One study compared fMRI and fTCD lateralisation estimates collected from 13 participants during performance of the WG task and found a near-perfect correlation between the techniques (r = .95; Deppe et al., 2000). However, the study was based on a relatively small sample of strongly left- (n = 7) and right- (n = 6) lateralised participants, and therefore the strong correlation may reflect an overestimation of the true agreement between fMRI and fTCD. Indeed, all subsequent studies, which have

[1] In the Jansen et al. (2004) study, a range of fMRI lateralisation indices were calculated based on: 1) the volume of significantly activated brain region (i.e., the number of activated voxels above a statistical threshold), as well as 2) the magnitude of the fMRI signal change between activation and the control task, within a region of interest. Based on the latter approach, which is arguably a more robust and reliable approach to calculating fMRI lateralisation indices (Bradshaw, Bishop, & Woodhead, 2017; Jansen et al., 2006), the correlation between fMRI (for the parietal region) and fTCD was high (r = .69).

included a higher number of low lateralised (i.e., bilateral) participants, have reported lower correlations. For example, a study comparing fMRI and fTCD lateralisation estimates collected from 22 participants during performance of the WG task reported a high correlation between the two techniques (r_s = .75; Somers et al., 2011), albeit lower than the .95 correlation initially reported (Deppe et al., 2000). Another study comparing language lateralisation determined by fMRI (during the WG, auditory naming and semantic matching tasks) and fTCD (during the WG task) in 32 participants found only moderate correlations, with the strongest agreement for auditory naming (r_s = .59), followed by WG (r_s = .49), and finally semantic matching (r_s = .44; Bruckert, 2016). Of the three studies which have investigated the agreement between fMRI and fTCD in the assessment of spatial attention lateralisation, correlations range from high to low (Hattemer et al., 2011; Jansen et al., 2004; Schmidt et al., 1999). A study comparing fMRI and fTCD lateralisation estimates in 15 participants during the Landmark task found a high correlation (r = .69) between the two techniques (Jansen et al., 2004). However, another study comparing fMRI-fTCD lateralisation estimates during a visuospatial 'spot-the-difference' task reported only a moderate correlation (r_s = .54; Schmidt et al., 1999). Finally, the weakest correlation reported between fMRI and fTCD lateralisation estimates (r = .34) was found in a study of 20 participants who performed a mental rotation task (Hattemer et al., 2011). The imperfect concordance between lateralisation estimates measured by fMRI and fTCD could be explained by several potential sources of variability, including: 1) variance in the calculation of fMRI lateralisation indices, 2) variance in individual lateralisation estimates over time, 3) differences between fMRI and fTCD experimental tasks, 4) differences between the fMRI-BOLD and fTCD-CBFV signals, and 5) differences between the fMRI and fTCD laboratory environments.

Variance in the calculation of fMRI lateralisation indices.

While there are standardised methods for calculating fTCD lateralisation indices (LIs; Badcock & Groen, 2017), the approach to calculating fMRI-LIs is highly inconsistent (Bradshaw, Bishop, & Woodhead, 2017). FMRI-LIs are calculated as the difference between activity in the left (L) and right (R) hemispheres, divided by the total activity across both hemispheres: $fMRI_{LI} = (L–R)/(L+R)$. FMRI-LIs range from 1 (strong left lateralisation) to -1 (strong right lateralisation). Of concern is lack of standardised protocols for calculating the L and R terms in the fMRI-LI formula. For example, the L and R terms can be based on the volume of significantly activated voxels (three-dimensional units of measurement) in each hemisphere above a given statistical threshold. Typically, above a certain threshold, fewer active voxels will remain in the non-lateralised hemisphere, resulting in an increase or decrease in the LI towards 1 or -1, respectively. Below a certain threshold, many active voxels will remain in the non-lateralised hemisphere, resulting in a change in the LI towards zero (i.e., bilateral activation). Alternatively, the L and R terms can be based on the magnitude of task-induced mean signal intensity change, which is threshold-independent. This is arguably the more robust and reliable approach to calculating fMRI-LIs (Bradshaw et al., 2017; Jansen et al., 2006). Regardless of whether the LI calculation is based on the volume or magnitude of neural activity, one still must decide if the analysis should focus on activity in a specific region of interest or in the entire hemisphere. Of the six fMRI-fTCD lateralisation comparison studies, no two studies used the same method for calculating fMRI-LI L and R terms, nor focused the analysis on the same brain region of interest. Therefore, the variability in the calculation of fMRI-LIs could partially explain discrepancies between fMRI and fTCD lateralisation estimates.

Variance in individual lateralisation estimates over time.

Discordance between fMRI and fTCD lateralisation estimates could also be due to variance in individual lateralisation estimates over time. For example, circadian rhythms (Ameriso, Mohler, Suarez, & Fisher, 1994) and neurostimulants, such as nicotine (Kodaira et al., 1993) and caffeine (Casiglia et al., 1991), have been shown to influence the cerebral blood flow response which could, in turn, influence the reliability of lateralisation estimates between assessments. Furthermore, a recent study found that lateralisation estimates were less reliable in women, with a shift towards bilateral lateralisation estimates around menstruation and a significant reversal afterwards (Helmstaedter, Jockwitz, & Witt, 2015). Behavioural and psychological factors could also influence the reliability of lateralisation estimates. Repeated performance of the same cognitive task could improve behavioural performance, reduce cognitive demands, and influence motivation and cooperation during the assessment. Furthermore, individuals may use different cognitive strategies when repeating the same task. All of these factors could conceivably lead to systematic, and possibly unihemispheric, changes in the cerebral blood flow response during successive lateralisation assessments (Knecht, Deppe, Ringelstein, et al., 1998). Therefore, individual variance in lateralisation estimates over time may also partially explain discordance between fMRI and fTCD lateralisation estimates.

Differences between fMRI and fTCD experimental tasks.

When comparing the relationship between fMRI and fTCD lateralisation estimates, it is ideal to use the same experimental task for both assessments to eliminate task differences as a potential confound. However, in all six fMRI-fTCD lateralisation comparison studies, the fMRI and fTCD tasks were poorly matched on several aspects, including the quantity and choice of task stimuli, the mode of stimulus presentation, the structure of the trials, and if and how they checked for task compliance (Bruckert, 2016; Deppe et al., 2000; Hattemer et al.,

2011; Jansen et al., 2004; Schmidt et al., 1999; Somers et al., 2011). Furthermore, one study compared fMRI and fTCD lateralisation estimates using entirely different language paradigms: WG, auditory naming and semantic matching tasks for the fMRI assessment and WG only for the fTCD assessment (Bruckert, 2016). The moderate fMRI-fTCD correlations found in this study are perhaps unsurprising given the different cognitive demands required by the tasks: WG requires phonological fluency, auditory naming requires sentence comprehension, and semantic matching requires the retrieval of semantic knowledge. This variability is problematic as lateralisation estimates can vary between experimental tasks requiring different cognitive demands (Badcock, Nye, & Bishop, 2012; Bishop, Watt, & Papadatou-Pastou, 2009; Buchinger et al., 2000; Stroobant, Buijs, & Vingerhoets, 2009). Therefore, poorly matched experimental tasks may also explain discrepancies between fMRI and FTCD lateralisation estimates.

Differences between fMRI and fTCD signals.

Furthermore, perfect agreement between fMRI and fTCD lateralisation estimates may not be reached as the two techniques record different phenomena. Both infer changes in neural activity by measuring changes in blood flow to regions of the brain. However, as described above, fMRI measures ratio changes of oxygenated to deoxygenated blood flow (i.e., the BOLD signal) within brain regions of interest whereas fTCD measures changes in CBFV through the cerebral arteries. It has been suggested that fTCD may be too insensitive to measure lateralisation precisely as its spatial resolution is restricted to the vascular territories of the cerebral arteries (Cai et al., 2013). As such, the fMRI-BOLD and fTCD-CBFV signals may not be entirely complementary.

Differences between fMRI and fTCD laboratory environments.

Finally, divergence between fMRI and fTCD lateralisation estimates may be partially explained by the fact that they are measured in considerably different laboratory

environments. As previously described, fMRI occurs in a noisy, narrow tube while participants lie supine and motionless on an examination bed, whereas fTCD (and, more broadly, most cognitive psychology experiments) occurs in a quiet, unconfined space while participants sit upright in a chair. Stress induced by fMRI acoustic noise and confined space (Raz et al., 2005), as well as fatigue induced by lying supine (Ouchi, Okada, Yoshikawa, Nobezawa, & Futatsubashi, 1999), could alter the blood flow response, thereby leading to differences between fMRI and fTCD lateralisation estimates. The following section explores the potential of fMRI acoustic noise, confined space and supine posture to confound the measurement of lateralisation.

Acoustic noise.

Inherent to fMRI scanning is intense acoustic noise and 1 to 1.5 kHz of scanner vibration (Raz et al., 2005). Acoustic noise, which manifests as loud knocking and beeping sounds, is generated each time an image is acquired. To generate images, fMRI uses both the static magnetic field of a permanent magnet, as well as temporally varying magnetic field gradients to manipulate the hydrogen nuclei in the body (Ravicz, Melcher, & Kiang, 2000). Three sets of coils are used to set up the magnetic field gradients. When a current is passed through these coils, the resulting magnetic forces on the coils cause them to flex, thereby producing perceivable acoustic noise. FMRI based on the echo-planar imaging protocol (a widely used high-speed imaging technique that involves rapid gradient switching) can reach a sound pressure level of up to 135 dB. For reference, 135 dB is equivalent to the noise levels produced by an air raid siren ("Noise Level Chart," n.d.). Ear protection, including earplugs and earmuffs, must be fitted to reduce noise levels by approximately 30 to 40 dB, but are insufficient to achieve quiet conditions (Fisher & Williams, 2013; Ravicz & Melcher, 1998). FMRI acoustic noise can cause annoyance, impede verbal communication, induce anxiety, intensify mental fatigue, and impair cognitive performance (McJury & Frank, 2000; Raz et

al., 2005). Short-term laboratory studies have found that exposure to environmental noise is associated with arousal of the sympathetic nervous system (associated with the body's 'fight-or-flight' stress response) and the endocrine system, causing increased blood pressure, changes in heart rate and the release of stress hormones (Basner et al., 2014). A recent study investigating the influence of acoustic noise on the fMRI-BOLD response during a verbal working memory task found that increased scanner noise produced increased BOLD responses bilaterally in the temporal, occipital and prefrontal cortices, and the cerebellum, as well as decreased BOLD responses bilaterally in the frontal cortices and subcortical grey matter regions (Tomasi, Caparelli, Chang, & Ernst, 2005). Based on this finding, it is possible that fMRI stressors, like noise, may put additional pressure on cognitive resources, leading to compensatory bilateral blood flow. As such, fMRI acoustic noise may confound the measurement of lateralisation, which could, in turn, explain differences between fMRI and fTCD lateralisation estimates.

Confined space.

In addition to noise, stress induced by physical space confinement during fMRI may also confound the measurement of lateralisation. To conduct a brain scan, subjects are typically inserted head first into a narrow bore (approximately 55 to 70 cm in diameter and 90 to 200 cm in length) until the head is at the centre of the tunnel. Subjects must then remain motionless for the duration of the assessment (typically up to and exceeding one hour) to prevent motion-related artefacts (Eshed, Althoff, Hamm, & Hermann, 2007). The head and neck are enclosed in a head coil (similar to a football helmet) which acts as an antenna to generate high quality images of the brain. The head coil also restricts head movement, blocks peripheral vision and limits the visual field to a mirror, mounted on the head coil, which reflects the stimulus computer screen. Between 1% and 15% of all patients undergoing fMRI suffer from claustrophobia – an extreme or irrational fear of enclosed or confined spaces –

and cannot be imaged, or else require sedation to complete the scan (Dewey, Schink, & Dewey, 2007). Furthermore, up to 30% of participants in fMRI experiments show some form of anxiety preceding or during the scan (Robinson, 1996). A large-scale cohort study investigating the incidence of fMRI-related claustrophobia found that the majority of claustrophobia-related premature fMRI terminations occurred during head and neck scans (Eshed et al., 2007). It is likely that the restrictive head coil, used only for head and neck scans, may intensify a sense of confinement, leading to heightened anxiety (Murphy & Brunberg, 1997). As with noise, stress induced by performing a cognitive task in a claustrophobic environment could increase strain on cognitive resources, leading to compensatory bilateral activation. Again, this could account for differences between fMRI and fTCD lateralisation estimates.

Supine posture.

Finally, fatigue induced by lying supine during fMRI assessment may also confound the measurement of lateralisation. Supine posture stimulates the baroreceptors (sensors in blood vessels which are sensitive to changes in blood pressure) which causes the suppression of the sympathetic nervous system, associated with the 'fight-or-flight' stress response, and arousal of the parasympathetic nervous system, associated with the 'rest-and-digest' relaxation response (Lifshitz, Thibault, Roth, & Raz, 2017). Supine posture during fMRI is known to cause drowsiness, particularly in elderly participants and pathological populations (Ray, Phillips, & Weir, 1993), which likely impairs attention and compliance during performance of cognitive tasks. Compared to lying supine, sitting upright has been associated with increased blood flow to visual areas (Ouchi et al., 1999), greater high-frequency activity in widespread parieto-occipital regions (Lifshitz et al., 2017) and increased cortical activity (Spironelli, Busenello, & Angrilli, 2016). These findings support the idea that body posture can influence estimates of neural activity.

Overall, it is possible that stress triggered by fMRI acoustic noise and confined space, as well as fatigue triggered by lying supine during fMRI, may alter the cerebral blood flow response and confound the measurement of lateralisation. As such, differences between the fMRI and fTCD laboratory environments may partially account for differences between fMRI and fTCD lateralisation estimates.

The Present Study

This is the first study to investigate the influence of the fMRI and fTCD laboratory environments, which differ in terms of noise, space and posture, on the measurement of language lateralisation. Across two experiments, fTCD was used to measure the consistency of language lateralisation estimates while participants performed the WG task either twice in the same fTCD environment (i.e., control condition), or once in an fTCD environment and then in a simulated fMRI environment (i.e., experimental condition). These two repetitions of the WG task will hereafter be referred to as Time 1 (T1) and Time 2 (T2). I chose to measure language lateralisation using fTCD because it is inherently silent and allows for manipulation of space and postural constraints. Using fTCD also allowed me to control for signal and LI calculation variance inherent when comparing the fMRI-BOLD and fTCD-CBFV signals (which would be impossible with fMRI).

Experiment 1.

In Experiment 1, I used a repeated-measures design to investigate the consistency of language lateralisation estimates while participants performed the WG task twice in the same fTCD laboratory environment (i.e., control condition). I expected:

1. No difference between T1 and T2 LIs;
2. High LI test-retest reliability between T1 and T2; and
3. High stability of categorical lateralisation (i.e., left, bilateral and right) between T1 and T2.

This was an exploratory experiment, conducted to determine the most appropriate design to incorporate in Experiment 2.

Experiment 2.

In Experiment 2, I used a mixed design and compared the change in language lateralisation estimates when participants performed both T1 and T2 in an fTCD environment (control group; the same condition as in Experiment 1), or T1 in and fTCD environment and T2 in a simulated fMRI environment (experimental group). Relative to the control group, I expected the experimental group to show:

1. Greater absolute change in LIs between T1 and T2;
2. Poorer LI test-retest reliability between T1 and T2; and
3. Poorer stability of categorical lateralisation between T1 and T2.

Such findings would suggest that environmental confounds, such as noise, space and posture, may partially account for the discordance between fMRI and fTCD lateralisation estimates.

Experiment 1

In Experiment 1, fTCD was used to measure the consistency of language lateralisation estimates when participants performed the WG task twice, consecutively, in an fTCD environment: a quiet, spacious room, sitting upright.

Method

Sample size and power.

As I was expecting a high LI test-retest reliability between T1 and T2, I determined an approximate sample size based on Cohen's (1992) guidelines for the significance of a product-moment correlation coefficient *r*. Cohen recommends that, for a large effect size with power of .80 and alpha of .05, the necessary sample size is 28. In anticipation that I

would likely need to exclude participants (e.g., due to measurement error or early experiment termination), I tested 34 participants overall.

Participants.

Thirty adults (seven males and 23 females) with a mean age of 20.21 years (*SD* 3.02, min = 17.10, max = 29.50) were included in the final sample. An additional four individuals were tested but excluded to measurement artefacts (one case), early experiment termination due to a headache (one case) or failure to detect a suitable acoustic temporal bone window to record an fTCD signal (two cases). Based on self-report (i.e., asking participants which hand they use to write with), the sample included five left-handers and 25 right-handers. Descriptive statistics for three additional handedness assessments (two questionnaires and one behavioural measure; described in the Materials section below) are displayed in Table 2 to provide a more complete description of the sample. All participants were fluent in English, had normal or corrected-to-normal vision, and provided written informed consent prior to testing. The study was approved by the Macquarie University Human Research Ethics Committee (reference number: 5201500074).

Table 2

Descriptive Statistics for the Handedness Assessments (EHI, FLANDERS and QHP), Experiment 1

						Frequencies (%)		
	Mean	Median	SD	Min	Max	Left	Mixed	Right
EHI	57.37	85.71	66.77	-100	100	4 (13.3)	8 (26.7)	18 (60.0)
FLANDERS	6.53	10.00	7.37	-10	10	5 (16.7)	0	25 (83.3)
QHP	0.25	0.41	0.34	-0.50	0.50	4 (13.3)	7 (23.3)	19 (63.3)

Note. EHI = Edinburgh Handedness Inventory (Oldfield, 1971); FLANDERS = The Flinders Handedness survey (Nicholls, Thomas, Loetscher, & Grimshaw, 2013); QHP = Quantification of Hand Preference (Bishop, Ross, Daniels, & Bright, 1996) task. These handedness assessments are described in the Materials section below.

Materials.

Handedness assessments.

I assessed handedness for the purpose of describing the sample, as well as to compare this study to previous research. How to best measure handedness is a matter of contention. Handedness can be measured as a categorical variable by asking individuals if they are left- or right-handed, or ambidextrous. Alternatively, handedness can be quantified as a continuous variable using questionnaires or behavioural measures. For the present study, I used a self-report categorical measure of handedness (i.e., asking participants which hand they use to write with), and three continuous measures of handedness: the Edinburgh Handedness Inventory (EHI; Oldfield, 1971), the Flinders Handedness survey (FLANDERS; Nicholls et al., 2013), and the Quantification of Hand Preference task (QHP; Bishop et al., 1996). Despite the immense popularity of the EHI, its instructions have been widely misunderstood, resulting in unclear responses (Fazio, Coenen, & Denney, 2012). Therefore, I also administered the FLANDERS, which provides a measure of skilled handedness that is easy to both administer and understand. Finally, it has been suggested that the best way to quantify hand preference is to observe how readily a person will use their non-preferred hand in a reaching task (Bishop et al., 1996). Therefore, I also included the QHP as a behavioural measure of hand preference.

Edinburgh Handedness Inventory (EHI).

An abbreviated version of the Edinburgh Handedness Inventory (Oldfield, 1971; see Appendix A) was used to measure the degree of hand preference for the following 10 activities: writing, drawing, throwing, using scissors, using a toothbrush, using a knife (without a fork), using a spoon, using a broom (upper hand), striking a match (hand holding the match), and opening a box (hand holding the lid). Additional eye and foot preference questions were not included. For each activity, participants indicated their hand preference by

marking a plus in the left and/or right columns. Two pluses in the left or right column indicated a strong left or right hand preference, one plus in the left or right column indicated a less-strong left or right hand preference, and a plus in the left and right columns indicated no hand preference. The number of pluses in the left (L) and right (R) columns were summed, separately, and a handedness quotient was calculated as (R-L)/(R+L)*100. Scores ranged from -100 (extreme left-handedness) to 100 (extreme right-handedness). Individuals were categorised into three handedness groups according to pre-defined cut-offs (Dragovic, 2004): left-handed (scores less than -70), mixed-handed (scores between -70 and 70), and right-handed (scores greater than 70).

Flinders Handedness survey (FLANDERS).

The FLANDERS (Nicholls et al., 2013; see Appendix B) requires individuals to place a tick in columns labelled ‘left’, ‘either’ or ‘right’ to indicate their hand preference for the following 10 activities: writing, using a spoon when eating, holding a toothbrush when cleaning teeth, holding a match when striking, holding a rubber when erasing, holding a needle when sewing, holding a knife when buttering bread, hammering, holding a peeler when peeling an apple, and drawing. A hand preference score was calculated by assigning values of -1, 0 and +1 to responses of ‘left’, ‘either’ or ‘right’, respectively. Values for the 10 items were summed. Scores ranged from -10 (extreme left-handedness) to 10 (extreme right-handedness). Individuals were categorised into three handedness groups according to pre-defined cut-offs (Nicholls et al., 2013): left-handed (scores less than -5), mixed-handed (scores between -5 and 5), and right-handed (scores greater than 5).

Quantification of Hand Preference task (QHP).

For the QHP (Bishop et al., 1996), stacks of three playing cards were placed face down on a table at seven locations (numbered one to seven) along an arc at successive 30-degree intervals (see Figure 1). Each stack was approximately 40 cm from the participant seated at

the table. Participants were asked to pick up a card from one of the seven locations, flip it over and place it directly in front of them in a stack. The location order was randomised but remained the same for all participants. There were no time constraints. The experimenter recorded the hand used to pick up each card. A hand preference score was calculated as (Number of right-hand reaches / total number of reaches) - 0.5. Scores ranged from -0.5 (extreme left-handedness) to 0.5 (extreme right-handedness). I categorised individuals into three handedness groups: left-handed (scores less than -0.25), mixed-handed (scores between -0.25 and 0.25), and right-handed (scores greater than 0.25).

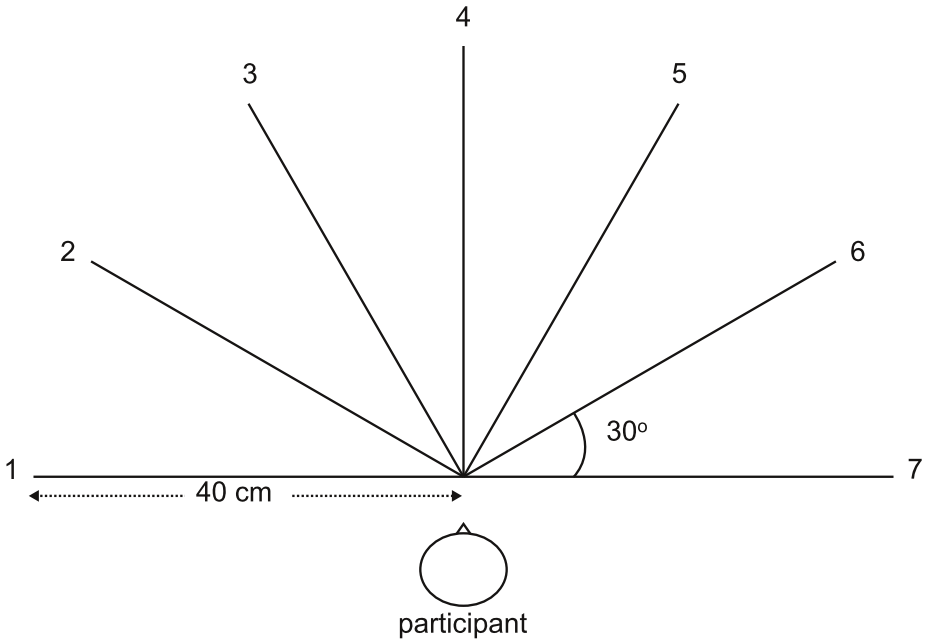

Figure 1. Quantification of Hand Preference (QHP) task. Participants reach for cards at each of the numbered locations and place them in a stack in front of them. Adapted from Bishop et al. (1996).

Word Generation task.

To assess language lateralisation, I used the gold standard Word Generation (WG) task, originally described by Knecht et al. (1998; 1996). All participants completed a total of 23 trials. Each trial ran for 60 s and consisted of the following four periods (see Figure 2 for a schematic diagram):

1. Relaxation (0 to 35 s): The message "relax" was displayed on the screen for 2 s followed by a blank screen for 33 s. This period is subdivided into normalisation (the first 20 s of the relaxation period to allow CBFV to return to baseline) and baseline (the final 15 s of the relaxation period, used to record baseline CBFV).
2. Preparation (35 to 40 s): A 100 ms cuing tone marked the start of this period, and was presented simultaneously with the message "clear mind", which was displayed for 2.5 s. This was followed by a blank screen for 2.5 s. The purpose of this period was to refocus the participants' attention following relaxation.
3. Silent word generation (40 to 55 s): A letter was displayed for 2.5 s, followed by a blank screen for 12.5 s. Overall, participants had 15 s to covertly generate as many words as possible beginning with the displayed letter. The letters Q, X, and Z were excluded due to the low frequency of words beginning with these letters in the English language. The remaining 23 letters of the alphabet were displayed once each in a different random order for each participant.
4. Say (55 to 60 s): A 100 ms cuing tone marked the start of this period, and was presented simultaneously with the message "say", which was displayed for 2.5 s. This was followed by a blank screen for 2.5 s. Overall, participants had 5 s to overtly report the words they had thought of during the silent word generation period. The purpose of this period was to check for task compliance.

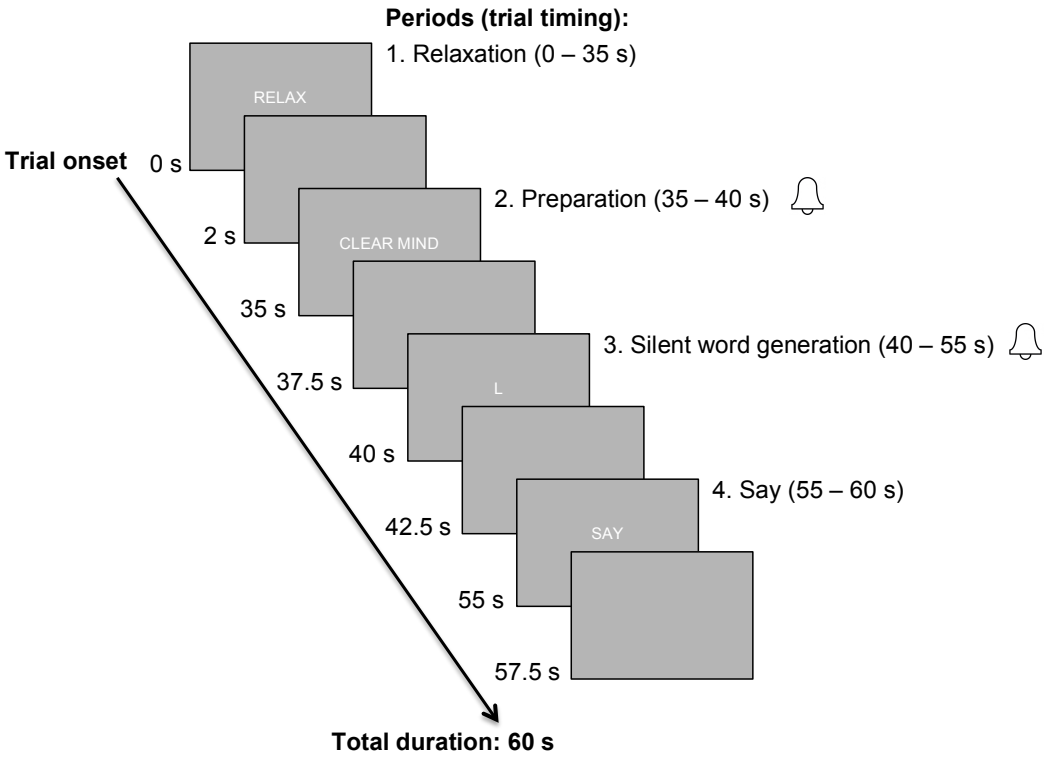

Figure 2. Schematic diagram of trial timing for the Word Generation task.

The stimuli were presented in white, centrally aligned, uppercase, size 30 Arial font over a grey background. The paradigm was programmed and presented in MATLAB 8.0.0.783 (Mathworks, Natick, MA, USA) using Psychtoolbox 3.0.10, revision 3187 (Brainard, 1997; Pelli, 1997). The task was presented on a desktop computer (Dell Optiplex 9010 with an Intel core i5-3470 processor running at 3.60 GHz) with a 21-inch LED monitor (Samsung S27ASA950 running at 120 Hz). Auditory cues were played through two speakers placed to the left and right in front of the participant.

Functional transcranial Doppler ultrasonography.

A Doppler ultrasonography device (Delica EMS-9U, Shenzen Delica Medical Equipment Co, Shenzen, China) was used to measure blood flow velocity through the left and right middle cerebral arteries as a measure of neural activity during the Word Generation tasks. A flexible headset held in place two 2-MHz transducer probes, one over each acoustic temporal bone window. Each probe was covered with adhesive conductive gel (Aquasonic® 100 by Parker) to enable an acoustically conducting bond between the skin and the probe.

The data were recorded at 125 Hz using Delica-9UA software. To time-lock task-related CBFV changes, event markers were inserted into the fTCD data file via a parallel port using MATLAB (available at http://apps.usd.edu/coglab/psyc770/IO32.html). Event markers corresponded to the onset of the silent word generation period when the letter was presented.

Design and procedure.

Participants were tested individually in a single session that ran for approximately 1 hour and 15 minutes. Participants were seated in front of a computer screen at a viewing distance of approximately 100 cm and fitted with the fTCD device. The experiment used a repeated-measures design whereby participants performed the WG task twice, consecutively, in the same fTCD laboratory environment: a quiet, spacious room where participants sat upright in a high back office chair. The sound pressure level of ambient noise at the participants' head (measured with a calibrated digital sound level meter (DIGITECH, QM-1589) was 36 dBA. The experimenter first explained the WG task instructions orally to participants and subsequently, the following instructions were presented on the screen:

Let your mind go blank. After a rest period, you will be instructed to "CLEAR MIND". When you see a letter on the screen, try to think of as many words as you can that begin with that letter. Do this silently. When you see the word "SAY", say aloud the words you thought of. When you see the word "RELAX", stop talking and let your mind go blank. It is important that you do not talk during the rest period. If you have any questions, please ask them now. If not, say "Ready".

The experimenter responded to any questions before starting the task. If the participant asked if they could repeat the words from T1 during T2, they were told to do their best to come up with new words. There was a 10-minute interval between T1 and T2 during which the experimenter administered the QHP, EHI and FLANDERS handedness assessments (in

this order). The experimental interest in hand preference was not explained to the participant until after the QHP was administered.

Data processing.

The fTCD data were processed using dopOSCCI (Badcock, Holt, Holden, & Bishop, 2012) version 3.0, an open access MATLAB-based summary suite for fTCD data (available at https://github.com/nicalbee/dopStep). DopOSCCI builds upon the data processing method described by Deppe et al. (1997) to maximise epoch retention and reliability. The following processing steps were performed:

Heart cycle exclusion.

The involuntary heart cycle is a major confound when measuring task-related changes in CBFV. Therefore, high frequency heart cycle artefacts were smoothed using MATLAB's linspace function.

Epoching and data trimming.

The continuous fTCD recordings were divided into epochs. Upper and lower values for each epoch, as well as baseline and period of interest timings were defined in relation to the event marker (set at 0 s), which corresponded to the onset of the silent word generation period when the letter was presented. Upper and lower values for each epoch were set from -15 to 25 s, baseline as -15 to -5 s, and the period of interest as 5 to 15 s. The timings took into account a 5-second lag in blood flow in response to ongoing stimuli (Aaslid, 1987). Blood flow lag occurs as it takes time for the vascular system to respond to the brain's need for blood (Rosengarten, Huwendiek, & Kaps, 2001). The data were trimmed to remove irrelevant recordings before the first and after the last epoch.

Normalisation.

To correct for potential differences between the left and right CBFV signals due to measurement artefacts, the data were normalised, on an epoch-by-epoch basis, to a mean of

100 using the following formula: (100 x data) / mean (data), where data refers to a collection of CBFV values. The formula shifts the average signal level while maintaining the variance. Measurement artefacts include left and right probe angle differences, participant movement, or signal change due to probe 'drift' (i.e., subtle, gradual movement in the probe position).

Baseline correction.

Baseline correction was conducted to remove low frequency artefacts that interfere with CBFV, such as breathing and variations in the sympathetic system activity and states of arousal (Deppe, Ringelstein, & Knecht, 2004). Mean data within the baseline period was subtracted from all other data points in the rest of the corresponding epoch, such that deviations from zero indicated activity increases or decreases in activity relative to baseline.

Epoch rejection.

The data within each epoch were screened for range artefacts (unusually high or low levels of activity), as well as signal separation artefacts (unusually large left-right signal differences). Epochs containing extreme CBFV values outside the range of 50 to 150 (i.e., ± 50% of the mean CBFV), or left-right signal differences greater than 14% which affected more than 1% of the data within each epoch, were excluded from the analysis. All participants had at least 20 of 23 suitable epochs for each task and were included for further analysis.

LI calculation and categorisation.

For each participant, left and right CBFV values were averaged across all acceptable epochs. Using these averages, LIs were calculated as the average left-minus-right CBFV difference within a 2-second interval, centred on the peak left-right difference within the period of interest. Positive LIs indicate left lateralisation, and negative LIs indicate right lateralisation. LI internal consistency was calculated by correlating the odd and even numbered epochs. LIs were also categorised as left, bilateral or right based on the overlap of

95% confidence intervals with zero. LIs were categorised as left if the lower interval was greater than zero, right if the upper interval was lower than zero, and bilateral if the interval was overlapping with zero.

Data analysis.

Frequentist analyses were performed with R-Studio (RStudio Team, 2015) and Bayesian analyses were performed with JASP (JASP Team, 2017).

Behavioural performance.

To check for practice and fatigue effects, I compared behavioural performance (i.e., number of words generated during the WG 'say' period) between T1 and T2 using a two-sided repeated-measures t-test (frequentist and Bayesian). With practice effects, I would expect improved behavioural performance during T2. With fatigue effects, I would worse behavioural performance during T2. With no practice or fatigue effects, I would expect no difference in behavioural performance between T1 and T2.

Language lateralisation data.

Normal probability (quantile-quantile) plots for the T1 and T2 LI data are displayed in Figure 3. The LI distribution violated the assumption of normality for T1, $W(30) = .90$, $p < .05$, but not for T2, $W(30) = .96$, $p = .300$. Both distributions appear to be affected by outliers. To account for the poor normality in T1 and to minimise the influence of outliers, I analysed the LI data using non-parametric tests.

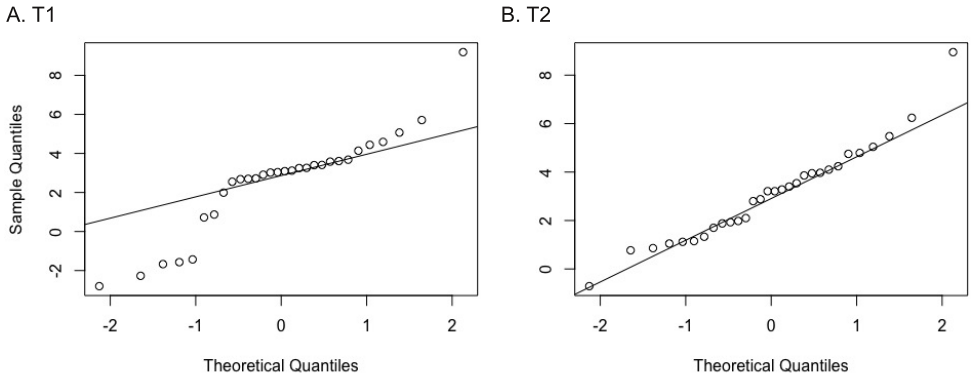

Figure 3. Normal probability (quantile-quantile) plots for the Time1 (T1; Panel A) and Time2 (T2; Panel B) lateralisation indices.

To assess whether there was a difference between T1 and T2 LIs, I used a two-sided Wilcoxon signed-rank test. To interpret a potential non-significant p-value, as well as to quantify the strength of evidence for the null and alternative hypotheses, I also conducted a two-sided Bayesian Wilcoxon signed-rank test (van Doorn, Ly, Marsman, & Wagenmakers, in preparation). This test does not assume normality and is robust with respect to outliers. I defined the alternative hypothesis prior using a default Cauchy distribution centred on zero and with the scale set at $r = 0.707$. This predicts that the most likely effect sizes are near zero, but large effect sizes are also possible. A more detailed explanation of the Bayesian statistics used in this study can be found in Appendix C.

To assess whether categorical lateralisation changed between T1 and T2, I used the related-samples McNemar's test. As McNemar's test requires binomial categories, I collapsed the three lateralisation categories (i.e., left, bilateral and right) into a binomial score (i.e., *Did categorical lateralisation change from T1 to T2: yes or no*) and compared it to no change.

Results

A summary of the Experiment 1 data can be found in Appendix D.

Behavioural performance.

A two-sided repeated-measures t-test failed to reject the null hypothesis of no difference in behavioural task performance (i.e., number of words reported in the 'say' period) between T1 ($M = 3.73$, $SD = 0.47$) and T2 ($M = 3.39$, $SD = 0.63$), $t(30) = -.89$, $p = .383$. A Bayesian two-sided repeated measures t-test revealed a $BF_{10} = 0.28$, indicating moderate evidence for the null hypothesis. Taking the inverse, the data were 3.6 times more likely under the null than under the alternative.

Language lateralisation.

The physiological CBFV response to the WG task during T1 and T2 is displayed in Figure 4. This reflects the baseline-corrected CBFV for the left and right hemispheres, as well as the left-minus-right difference, averaged across all acceptable epochs for T1 and T2, respectively. For both T1 and T2 there are four notable features:

1. A peak (between -5 and 0 s) that reflects a preparatory response to the ‘clear mind’ message;
2. Divergence between the left and right signals (between 5 and 15 s – i.e., the period of interest) that reflects a silent word generation response to the letter presentation;
3. A peak (between 15 and 20 s) that reflects a production response to the ‘say’ message;
4. A peak (between 20 and 25 s) that reflects an inhibitory response to the ‘relax’ message.

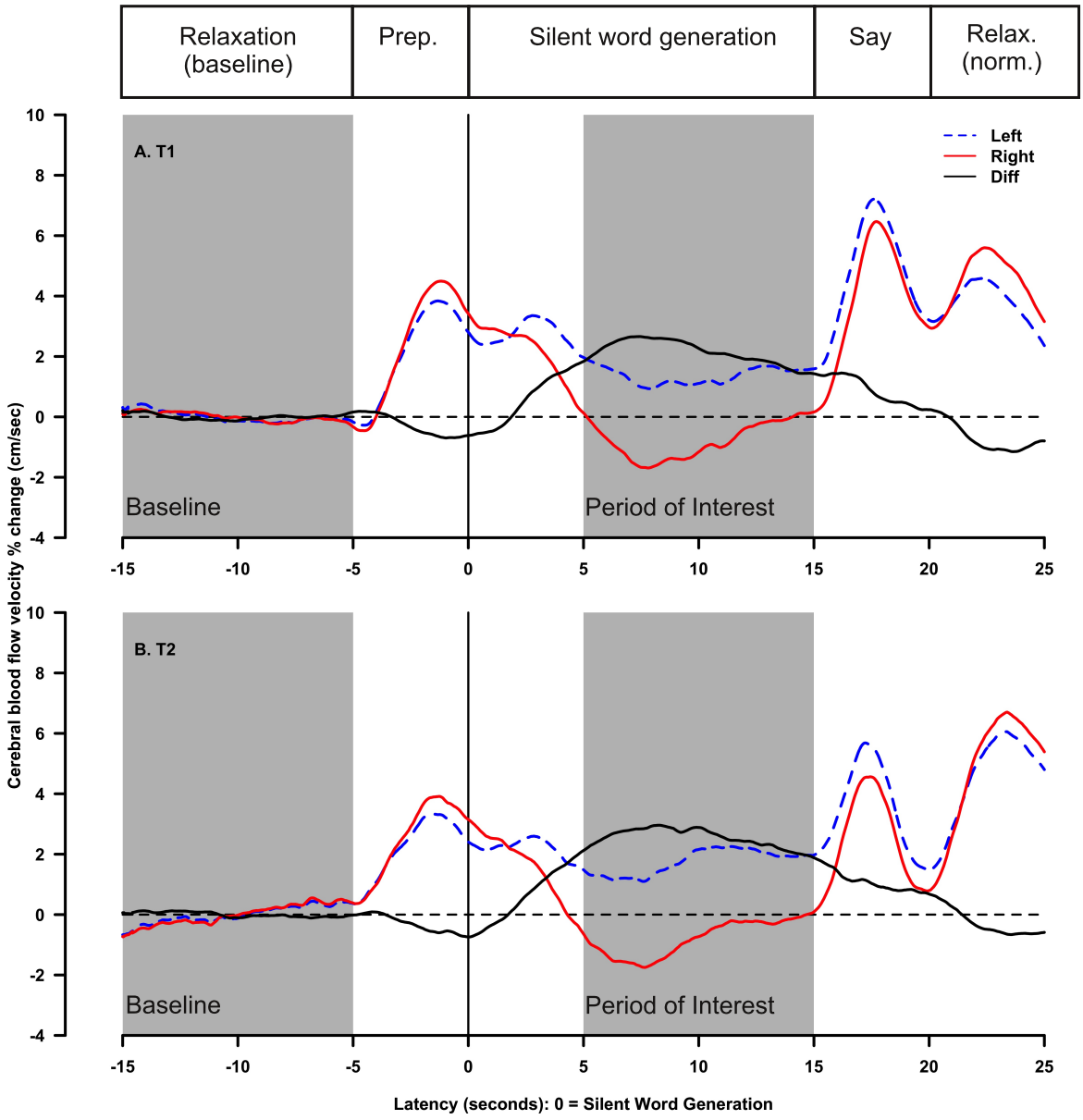

Figure 4. Group-averaged change in baseline-corrected cerebral blood flow velocity (CBFV) relative to the presentation of the letter (latency = 0 seconds) during the Word Generation task for the left (blue dashed line), right (red line), and left-minus-right (black line) signals as a function of time (in seconds). The baseline period (first grey panel: -15 to -5 s) and period of interest (second grey panel: 5 to 15 s) are displayed for reference. Panels A and B display the Time1 (T1) and Time2 (T2) data, respectively.

Comparison between T1 and T2 LIs.

Descriptive statistics for the T1 and T2 LIs are displayed in Table 3. A two-sided Wilcoxon signed-rank test failed to reject the null hypothesis of no difference between T1 and T2 LIs, $W = 289.00$, $p = .253$, matched rank biserial correlation = 0.24. A two-sided Bayesian Wilcoxon signed-rank test revealed a $BF_{10} = 0.50$. Taking the inverse, the data were 1.95 times more likely under the null hypothesis than under the alternative. While the *BF* falls short of Jeffreys' (1939) cut-off for substantial evidence (i.e., less than 1/3 or greater than 3), the Bayes factor still provides continuous, anecdotal evidence in support of the null hypothesis. This analysis is represented by the prior and posterior plots (see Appendix E).

Table 3

Descriptive Statistics for Lateralisation Indices (LIs) for the Two Repetitions (T1 and T2) of the Word Generation Task, Experiment 1

	Mean	Median	SD	Min	Max
T1	2.57	3.07	2.54	-2.80	9.19
T2	3.10	3.21	1.96	-0.71	8.95
Absolute Change	1.33	0.93	1.30	0.04	5.68

Note. T1 = Time 1; T2 = Time 2; Absolute Change = Absolute change in LIs from T1 to T2.

Reliability of LIs between T1 and T2.

Scatterplots for the T1 and T2 LI data are depicted in Figure 5. LI test-retest reliability was moderate, $r_s = 0.63$, $p < .001$. Internal consistency was high for T1, $r_s = .80$, $p < .001$, yet moderate for T2, $r_s = .68$, $p < .001$.

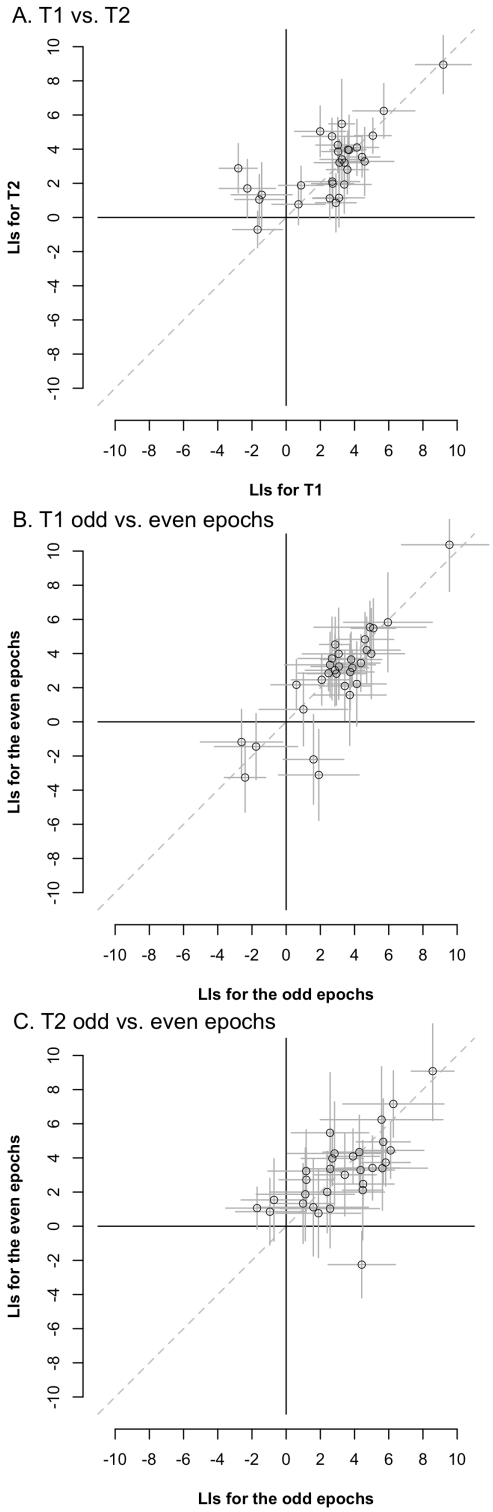

Figure 5. Scatterplots of the lateralisation indices (LIs) for the Word Generation task (N = 30). Panel A displays the Time1 (T1) vs. Time2 (T2) test-retest reliability. Panels B and C display the internal consistency (i.e., odd vs. even trials) for T1 and T2, respectively. A diagonal line is included for reference to consistent LI mapping between or within each task and 95% confidence intervals are displayed for each individual (light grey).

Comparison of categorical lateralisation between T1 and T2.

Categorical lateralisation frequencies are displayed in Table 4. Between T1 and T2, eight participants (26.7%) changed lateralisation categories: three from left to bilateral, three from right to bilateral, one from bilateral to left and one from bilateral to right. McNemar's test indicated that the number of participants whose categorical lateralisation changed between T1 and T2 was significantly different from zero (i.e., no change), $\chi^2 = 6.13$, $p < 0.05$.

Table 4

Categorical Lateralisation Frequencies (%) for the Two Repetitions (T1 and T2) of the Word Generation Task, Experiment 1

Condition	Left	Bilateral	Right
T1	23 (76.7)	3 (10)	4 (13.3)
T2	22 (73.3)	8 (26.7)	0

Note. T1 = Time 1; T2 = Time 2.

Discussion

In this experiment, I investigated the consistency of language lateralisation estimates when participants performed the WG twice, consecutively, in an fTCD laboratory environment. I expected: (1) no difference between T1 and T2 LIs, (2) high LI test-retest reliability between T1 and T2, and (3) high stability of categorical lateralisation between T1 and T2. A frequentist Wilcoxon signed-rank test failed to reject the null hypothesis of no difference between T1 and T2. Furthermore, a Bayesian Wilcoxon signed-rank test provided anecdotal evidence for no difference between T1 and T2 LIs. However, LI test-retest reliability between T1 and T2 was only moderate. The correlation appears to be weakened by several individuals, whose LIs switched from negative to positive between T1 and T2. Indeed, eight of 30 participants (26.7%) switched lateralisation categories between T1 and T2, and the amount of change was significantly different from zero. Given that a previous study has reported considerably higher LI test-retest reliability ($r = .95$, $p < .0001$) of fTCD

with the WG task (Knecht, Deppe, Ringelstein, et al., 1998), the test-retest reliability in the current study ($r_s = 0.63$, $p < .001$) was unexpectedly poor. Furthermore, LI internal consistency for T1 was high, $r_s = .80$, $p < .001$, yet only moderate for T2, $r_s = .68$, $p < .001$.

The current study differed from Knecht et al.'s study in that the measurement interval between T1 and T2 was considerably smaller: In the Knecht study, participants were reassessed 1 hour to 14 months after T1, whereas in the present study, participants were reassessed approximately 15 minutes after T1. It is possible that the almost immediate re-assessment in the current study may have increased the likelihood of carry-over effects between T1 and T2, leading to greater variability in lateralisation estimates between T1 and T2. While I found evidence of no difference in behavioural performance (i.e., the number of words generated) between T1 and T2, I had no measure of the cognitive strategies participants used to generate words, whether participants repeated words from T1 during T2, how participants felt (emotionally) during the T1 and T2, and how difficult participants found each WG task. It is possible that the moderate LI test-retest reliability and poor internal consistency of the T2 LIs may be associated with differences between T1 and T2 regarding cognitive strategy, emotional state and perceived task difficulty. For example, participants may have used different cognitive strategies to perform the WG task during T1 and T2, such as free association during T1 and memory/recall strategies during T2. Furthermore, participants may have felt stressed when performing the novel WG task during T1, and more relaxed due to practice during T2. Alternatively, participants may have felt motivated during T1 and bored or drowsy at T2. Finally, participants may have found T1 harder to perform than T2, or vice versa. Each of these factors could lead to systematic, and possibly unihemispheric changes in the CBFV response between T1 and T2 fTCD assessments (as noted by Knecht, Deppe, Ringelstein, et al., 1998).

To account for these potential sources of variability in Experiment 2, I explicitly asked participants about their experience of the tasks via a post-experiment interview. Specifically, I asked participants about: (1) the cognitive strategies they used to perform the WG task during T1 and T2, (2) how they felt during T1 and T2, and (3) how difficult they found the WG task during T1 and T2. Finally, to investigate whether changes in state anxiety between T1 and T2 might be a source of variability in lateralisation estimates, I also administered a state anxiety measure immediately after T1 and T2, respectively.

Experiment 2

In Experiment 2, I investigated whether the fMRI and fTCD laboratory environments, which differ in terms of noise, space and posture, differentially influence language lateralisation estimates. FTCD was used to measure CBFV while participants performed the WG task either twice (T1 and T2) in an fTCD environment (control group) or once in an fTCD environment (T1) and then in a simulated fMRI environment (T2; experimental group). In order to explain potential differences in lateralisation estimates between the two groups, I measured state anxiety and asked people about their experience of the tasks in a post-experiment interview. Relative to the control group, I expected the experimental group to show:

1. An increase in state anxiety between T1 and T2;
2. Greater absolute change in LIs between T1 and T2;
3. Poorer LI test-retest reliability between T1 and T2;
4. Poorer stability of categorical lateralisation between T1 and T2.

Method

The method for Experiment 2 was the same as Experiment 1 except for the differences described below.

Sample size and power.

For close comparison between Experiments 1 and 2, I planned to include 30 participants per group (60 overall). However, due to time constraints, I was only able to test 51 participants, and of these, seven were excluded (see below). Therefore, the final sample consisted of 22 participants per group (44 overall). While the sample was smaller originally planned, the Bayesian analysis indicated that the data were sensitive enough to provide substantial evidence (Dienes, 2014).

Participants.

Forty-four adults were included in the final sample. An additional seven individuals were tested but excluded due to measurement artefacts (three cases), early termination due to a headache (one case), and failure to detect a suitable acoustic temporal bone window to record an fTCD signal (three cases). The control group included 22 participants (six males and 16 females) with a mean age of 25.38 years (*SD* = 11.79, min = 18.10, max = 65.40). The experimental group included 22 participants (eight males and 14 females) with a mean age of 24.63 years (*SD* = 6.28, min = 18.00, max = 35.50). Based on self-report (i.e., asking participants which hand they use to write with), the control group included three left-handers and 19 right-handers, and the experimental group included two left-handers and 20 right-handers. Descriptive statistics for the EHI, FLANDERS and QHP are displayed in Table 5 to provide a more complete description of the sample. All participants were fluent in English, had normal or corrected-to-normal vision and provided written informed consent prior to testing. The study was approved by the Macquarie University Human Research Ethics Committee (reference number: 5201500074).

Table 5

Descriptive Statistics for the Handedness Assessments (EHI, FLANDERS and QHP) for the Control and Experimental Groups, Experiment 2

						Frequencies (%)		
	Mean	Median	SD	Min	Max	Left	Mixed	Right
Control								
EHI	58.27	75.73	55.38	-100	100	1 (4.5)	9 (40.9)	12 (54.5)
FLANDERS	6.96	10	6.55	-10	10	3 (13.6)	0	19 (86.4)
QHP	0.17	0.38	0.38	-0.50	0.50	5 (22.7)	5 (22.7)	12 (54.5)
Experimental								
EHI	63.26	76.97	45.80	-83.33	100	1 (4.5)	9 (40.9)	12 (54.5)
FLANDERS	7.77	9.50	5.49	-10	10	2 (9.1)	0	20 (90.9)
QHP	0.26	0.33	0.26	-0.36	0.50	1 (4.5)	10 (45.5)	11 (50.0)

Note. EHI = Edinburgh Handedness Inventory (Oldfield, 1971); FLANDERS = The Flinders Handedness survey (Nicholls et al., 2013); QHP = Quantification of Hand Preference Task (Bishop et al., 1996). These handedness assessments are described in the Experiment 1 Methods section.

Materials.

The State-Trait Anxiety Inventory for adults.

The state portion of the STAI for adults (Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983; see Appendix F) was used to assess participants' current self-rated anxiety levels immediately following each WG task. Participants were required to rate their strength of agreement to 20 items (e.g., *'I feel calm'* and *'I am tense'*) using a four-point Likert scale (1 = not at all; 2 = somewhat; 3 = moderately so; 4 = very much so). Half of the items (1, 2, 5, 8, 10, 11, 15, 16, 19 and 20) were reverse scored and values for the 20 items were summed. Scores range from 20 to 80, with higher scores indicating greater state anxiety. Internal consistency for STI (Form Y) is high (Cronbach's α ranging from .86 to .95) while test-retest reliability is relatively low (median r = .33), reflecting the influence of unique

situational factors on present anxiety levels (Spielberger et al., 1983). Considerable evidence supports the construct and concurrent validity of the STAI (Spielberger, 1989).

Laboratory environments.

The control group were tested in the same fTCD laboratory environment as described in Experiment 1. The following details apply only to the experimental group. The experimental group were tested in a room in the basement of the building to prevent the noise from the fMRI simulation from disturbing building occupants. The laboratory setup is depicted in Figure 6. The tasks were presented on a laptop computer (Apple 15" High-Res Matte Display with an Intel Core i7 processor running at 2.2Ghz). Auditory cues were played through the internal laptop speakers for T1 and through earphones (SHURE) for T2. To time lock the task-related CBFV changes, event markers were inserted into the fTCD data file via a serial port (MMB Trigger Box, NEUROSPEC, powered by Arduino) using the serial port MATLAB function. Event markers corresponded to the onset of the silent word generation period when the letter was presented.

Figure 6. Laboratory setup for the experimental group (Experiment 2). Upper panels depict the fTCD environment and the lower panels depict the simulated fMRI environment.

FTCD laboratory environment.

The fTCD laboratory environment was a quiet, spacious room where participants sat upright in a high-back office chair. The sound pressure level of ambient noise at the participants' head was 42 dBA.

Simulated fMRI laboratory environment.

To simulate the fMRI scanner bore, I used a hollow, plastic-lined cardboard tube (sourced from The Tubeworks, Victoria, Australia; circular bore diameter = 71.1 cm, bore length = 100 cm, open at both ends). The tube dimensions closely matched the Macquarie University Hospital fMRI bore dimensions (Siemens 3-T MAGNETOM® Verio: circular bore diameter = 70 cm, bore length = 173 cm). The tube was attached to a head coil (sourced

from the Centre for Advanced Imaging, The University of Queensland) via a metal rail by Macquarie Engineering & Technical Services (METS). The tube slid horizontally back and forth over the head coil along the rail. The tube/head coil mechanism was secured to a padded, aluminium massage table (185 cm length x 90 cm width x 60 cm height) using two ratchet straps. Sections of the head coil that would be in close proximity to participants' temporal bone window (i.e., close to the tragus of the ear) were removed to avoid contact with the fTCD probes when participants were in the head coil. A lamp was attached to the top of the tube which served as a duress light. When participants were lying in the mock scanner, a light switch attached to a lamp was placed in their left hand and they were instructed to flick the switch if they wanted to pause or stop the experiment.

A digital recording of an fMRI echo-planner imaging sequence (sourced from Professor Robert Logie, The University of Edinburgh) was played through a speaker (JBL EON^{TM} Power15, Powered Speaker, JBL Professional, CA, USA) centred 50 cm behind the tube opening. The recording was 4 seconds in duration and played on a repeating cycle for the duration of the fMRI simulation. As the sound pressure level (*spl*) of fMRI acoustic noise varies between scanners, I chose to replicate the "loud" protocol used in the Tomasi et al. (2005) study: an *spl* of 104 dBA which was measured with an omnidirectional microphone at the entrance of the scanner (presumably this *spl* was the same at the participant's head inside the head coil). For more detail regarding the acoustic noise stimulus, see Appendix G.

Post-experiment interviews.

To gain a deeper understanding of participants' experience of the tasks and laboratory environment, I administered a semi-structured interview at the end of the experiment (see Appendix H for the interview questions). All participants were asked about: (1) the cognitive strategies they used to perform the WG task during T1 and T2, (2) how they felt during T1 and T2, and (3) how difficult they found the WG task during T1 and T2. Participants in the

experimental group were also asked about how the noise, space (i.e., tube and head coil) and lying down made them feel. Variance in cognitive strategies, emotional response and perceived task difficulty could lead to systematic, and potentially unihemispheric, changes in the CBFV response between T1 and T2 fTCD assessments (Knecht, Deppe, Ringelstein, et al., 1998). Therefore, interview responses may help to explain potential variance in the physiological response between T1 and T2.

Design and procedure.

Participants were tested individually in a single session that ran for approximately 1 hour and 30 minutes. The experiment used a mixed design, with group (random allocation to control or experimental) as the between-subjects factor, and time (T1 vs. T2) as the within-subjects factor. The control group performed the WG task twice (i.e., T1 and T2) in the fTCD environment (as in Experiment 1). The experimental group performed the WG task once in the fTCD environment (T1) and then in the simulated fMRI environment (T2). Immediately following both the T1 and T2 WG tasks, the experimenter administered the state portion of the STAI. The handedness assessments were administered after the T1 STAI was completed. Semi-structured interviews were conducted at the end of the experiment.

Prior to undergoing the fMRI simulation at T2, participants in the experimental group were told the following information:

1. The simulation will involve a loud, beeping noise throughout the task, and therefore you will be fitted with hearing protection.
2. A head coil will be placed above your face.
3. It is important to stay as still as possible during the task.
4. You will be given a volume control to hold in your right hand so that you can adjust the volume of the cuing tones associated with the WG task.

5. You will be given a light switch to hold in your left hand. Flick the switch if you want to pause or stop the experiment.

Participants were fitted with earplugs that were connected to earphones. Subsequently, participants were moved from the chair to the padded examination bed and guided to lie back slowly, lowering their head into the headrest. Participants were given the volume control and light switch, the head coil was placed above their face, and the tube was slid over their head and torso. A mirror mounted on the head coil allowed participants to see the task displayed on the stimulus presentation laptop screen. The laptop was positioned at the tube opening. The earphones were plugged into the laptop so that participants could hear the tones associated with the WG task over the simulated fMRI noise. When all the equipment was setup, the experimenter started both the WG task and the acoustic noise recording simultaneously. The fTCD probes remained connected to the Doppler system throughout this procedure so as to continuously monitor the signal during participant movements from chair to the bed. The fMRI noise prevented me from recording the number of words generated during the say period as an indicator of behavioural performance. I was still able to confirm task compliance as vocalisations were perceivable and I could see real-time speech-related artefacts in the fTCD signal. These artefacts are too small to disrupt the fTCD signal of interest.

Data analysis.

Absolute LI Change Scores

To test whether the degree of change in LIs from T1 to T2 was greater in the experimental group compared to the control group, I subtracted T1 from T2 LIs and converted these into absolute scores so that valence (i.e., left vs. right) did not confound the analysis. The distribution of absolute LI change scores violated the assumption of normality, $W(44) = 0.72$, $p < 0.05$, and appeared to be affected by outliers (Figure 7, Panel A). To

correct for the poor normality and to minimise the influence of outliers, a log transformation of the absolute LI change scores was performed. The log-transformed absolute LI change scores did not violate the assumption of normality, $W(44) = 0.96$, $p = .13$ (Figure 7, Panel B). Therefore, I analysed the log-transformed absolute LI change scores using parametric tests. Hereafter, I will refer to the transformed variable as absolute LI change.

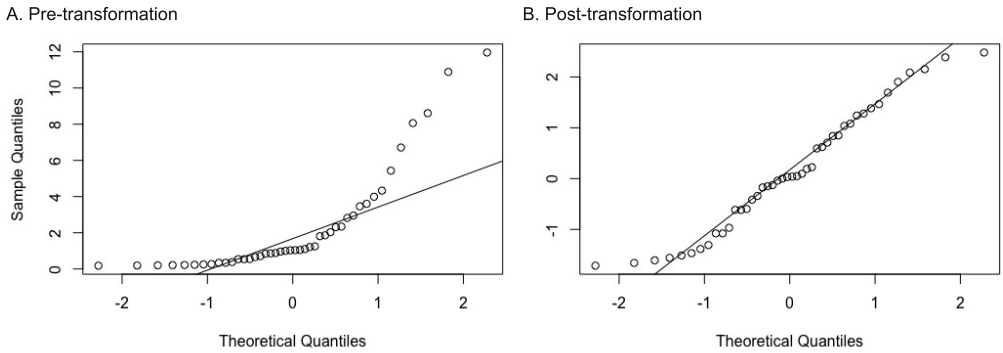

Figure 7. Normal probability (quantile-quantile) plots for the absolute LI change scores before (Panel A) and after (Panel B) the log transformation.

To assess whether the degree of absolute change in LIs from T1 to T2 was greater in the experimental group compared to the control group, I conducted a one-sided independent samples t-test. To interpret a potential non-significant p-value, as well as to quantify the strength of evidence for the null and alternative hypotheses, I also conducted a one-sided Bayesian independent samples t-test. I defined the alternative hypothesis prior using a folded Cauchy prior distribution, which predicts positive effect sizes only. The distribution was centred on zero with the scale set at a default value of $r = .707$.

Change in categorical lateralisation between T1 and T2.

To assess whether the change in categorical lateralisation from T1 to T2 was greater in the experimental group compared to the control group, I used a chi-square test. To conduct this test, I assigned individuals values of 0 (no change) and 1 (change) and compared rates between groups.

Post-experiment interviews.

Digital recordings of the post-experiment interviews, which were 1.5 to 7 minutes in duration, were transcribed verbatim. Transcripts were coded and categorised into response categories using NVivo (11.4.1). For each question, the frequency of references to each response category were summed for T1 and T2 by group.

Results

A summary of the Experiment 2 demographic, handedness, state anxiety, and language lateralisation data can be found in Appendix I (control: Table I1; experimental: Table I2).

State anxiety.

Descriptive statistics for the STAI scores are displayed in Table 6. Group and time did not significantly affect STAI scores: Group, $F(1,42) = 1.051$, $p = .332$, $\omega^2 = 0.001$; time, $F(1,42) = 0.623$, $p = .434$, $\omega^2 = 0.000$; group by time, $F(1,42) = 0.955$, $p = .334$, $\omega^2 = 0.000$.

Table 6

Descriptive Statistics for the Two (T1 and T2) Administrations of the State-Trait Anxiety Inventory (STAI) for the Control and Experimental Groups, Experiment 2

	Mean	Median	SD	Min	Max
Control					
T1	31.95	30.00	6.90	22	44
T2	34.09	35.50	9.66	20	60
Experimental					
T1	31.00	29.50	7.07	20	44
T2	30.77	29.00	8.03	20	52

Note. T1 = Time 1; T2 = Time 2.

Language lateralisation.

The physiological CBFV responses to the WG task during T1 and T2 for the control and experimental groups are displayed in

Figure 8. The figure depicts the baseline-corrected CBFV for the left and right hemispheres, as well as the left-minus-right difference, averaged across all acceptable epochs. These response patterns are consistent with Experiment 1.

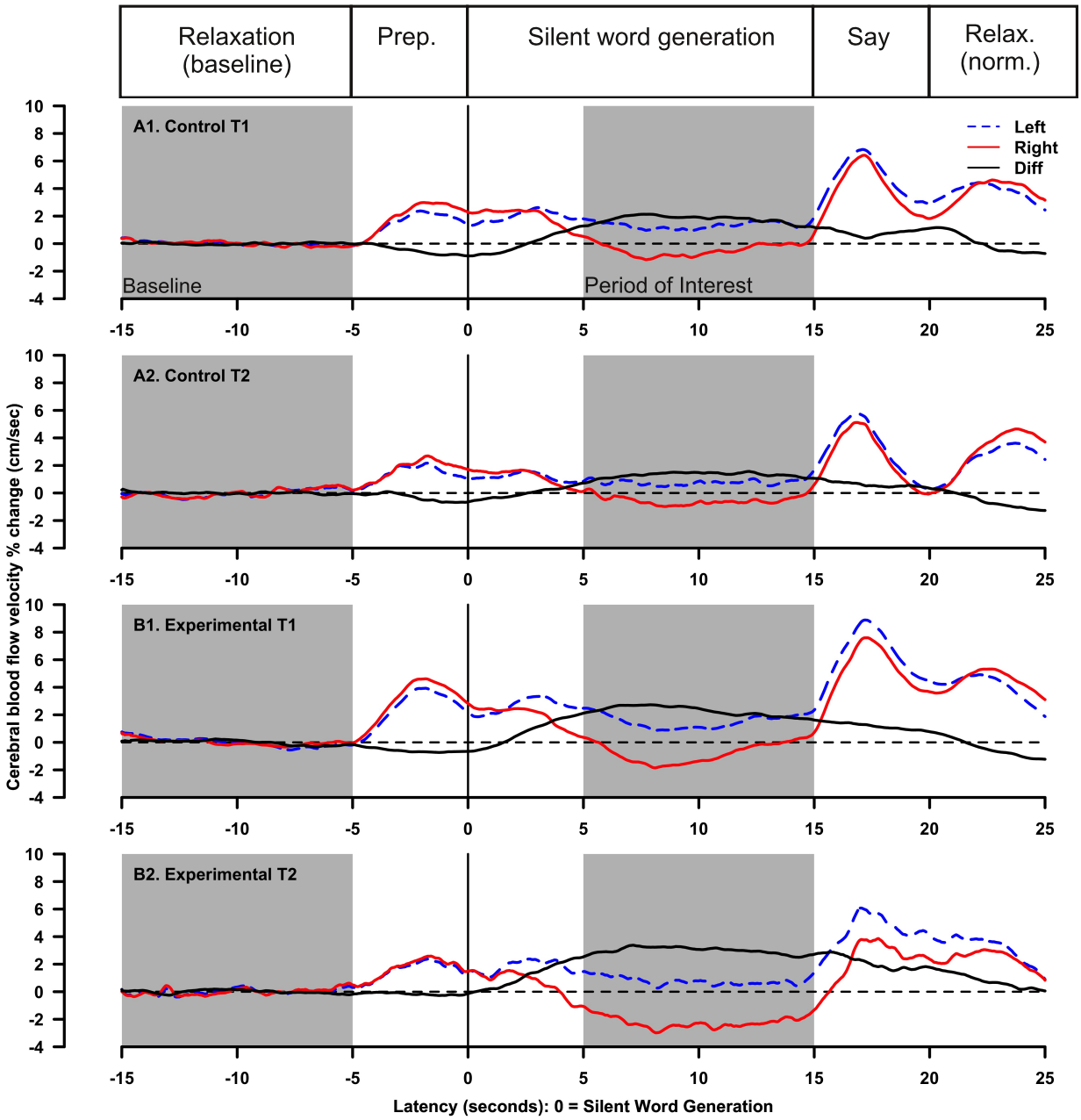

Figure 8. Group-averaged change in baseline-corrected cerebral blood flow velocity (CBFV) relative to the presentation of the letter (latency = 0 seconds) during the Word Generation task for the left (blue dashed line), right (red line), and left-minus-right (black line) signals as a function of time (in seconds). The baseline period (first grey panel: -15 to -5 s) and period of interest (second grey panel: 5 to 15 s) are displayed for reference. Panels A1 and A2 display the control group Time1 (T1) and Time2 (T2) data, respectively. Panels B1 and B2 display the experimental group T1 and T2 data, respectively.

Absolute change in LIs between T1 and T2

Descriptive statistics for the T1 and T2 LIs, as well as absolute LI change, are displayed in Table 7. A one-sided independent samples t-test failed to reject the null hypothesis of no difference in absolute LI change between the control and experimental groups, $t(42) = 1.12$, $p = .866$, $d = 0.34$. A one-sided Bayesian independent samples t-test revealed a $BF_{10} = 0.16$, indicating moderate evidence for the null hypothesis. Taking the inverse ($BF_{01} = 6.34$) demonstrates that the data were 6.34 times more likely under the null hypothesis than under the alternative (see Appendix J for Bayesian analysis plots).

Table 7

Descriptive Statistics for Lateralisation Indices (LIs) for the Two Repetitions (T1 and T2) of the Word Generation Task for the Control and Experimental Groups, Experiment 2

	Mean	Median	SD	Min	Max
Control					
T1	2.46	2.75	3.06	-3.38	8.48
T2	1.77	2.78	3.33	-8.81	6.67
Absolute Change	1.66	0.98	1.05	0.18	8.06
Experimental					
T1	2.76	2.55	2.11	-3.24	7.75
T2	3.80	3.94	3.54	-2.14	14.97
Absolute Change	2.92	1.90	3.55	0.20	11.96

Note. T1 = Time1; T2 = Time2; Absolute Change = Absolute change in LIs from T1 to T2.

Reliability of LIs.

Scatterplots for the LIs are depicted in Figure 9. For the control group, LI test-retest reliability was high, $r = .80$, $p < .001$, and internal consistency was high for both T1, $r = .86$, $p < .001$, and T2, $r = .81$, $p < .001$. For the experimental group, LI test-retest reliability was poor, $r = -.23$, $p = .331$, and internal consistency was high for both T1, $r = .747$, $p < .001$, and T2, $r = .81$, $p < .001$.

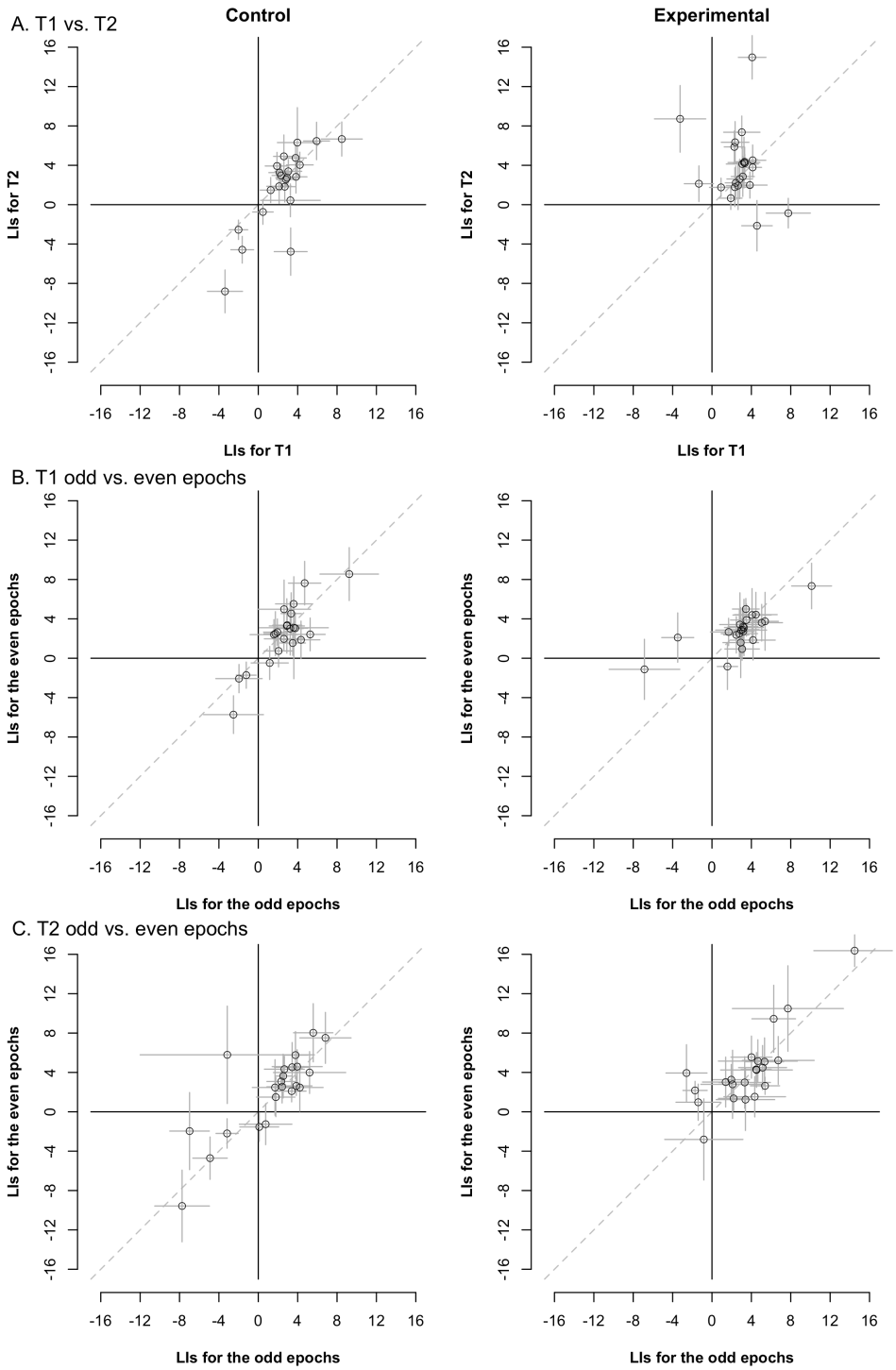

Figure 9. Scatterplots of the lateralisation indices (LIs) for the Word Generation task (N = 30) for the control (left-hand column) and experimental (right-hand column) groups, respectively. Panel A displays the Time1 (T1) vs. Time2 (T2) test-retest reliability. Panels B and C display the internal consistency (i.e., odd vs. even trials) for T1 and T2, respectively. A diagonal line is included for reference to consistent LI mapping between or within each task and 95% confidence intervals are displayed for each individual (light grey).

Change in categorical lateralisation.

Categorical lateralisation frequencies are displayed in Table 8. For the control group, two of 22 participants (9.1%) switched lateralisation categories between T1 and T2: one from left to bilateral, and the other from left to right. For the experimental group, eight of 22 participants (36.4%) switched lateralisation categories between T1 and T2: five from left to bilateral, two from bilateral to left, and one from right to left. There was a significant association between group and change in categorical lateralisation, $\chi^2(1) = 4.66$, $p < 0.05$, Cramer's $V = 3.25$, indicating significantly greater change in categorical lateralisation in the experimental group than the control group.

Table 8

Categorical Lateralisation Frequencies (%) for the Two Repetitions (T1 and T2) of the Word Generation Task for the Control and Experimental Groups, Experiment 2

	Left	Bilateral	Right
Control			
T1	18 (81.8)	1 (4.5)	3 (13.6)
T2	16 (72.7)	2 (9.1)	4 (18.2)
Experimental			
T1	19 (86.4)	2 (9.1)	1 (4.5)
T2	17 (77.3)	5 (22.7)	0 (0)

Note. T1 = Time 1; T2 = Time 2.

The high proportion of categorical lateralisation switching in the Experiment 1 sample (8/30), as well as in the Experiment 2 experimental group (8/22), may be explained by a high proportion of participants whose LIs were close to the threshold between categories (i.e., close to zero). Conversely, the low proportion of categorical lateralisation switching in the Experiment 2 control group (2/22) may be explained by a high proportion of participants whose LIs were strongly lateralised and further from the zero threshold. To explore this possibility, I compared absolute LIs for T1 between the three groups ($M_{exp1} = 3.22$, $SD =$

1.66; $M_{exp2\text{-}control}$ = 3.09, *SD* = 1.66; $M_{exp2\text{-}experimental}$ =3.18, *SD* = 1.37) to determine if they differed in their strength of lateralisation. However, a one-way analysis of variance failed to reject the null hypothesis of no difference between the group means, $F(2, 71) = 0.04$, $p = .961$, $\eta^2 = 0.001$, and a Bayesian ANOVA found substantial evidence for no difference, $BF_{10} = .12$. Therefore, the higher proportion of categorical lateralisation switching in Experiment 1 and in the Experiment 2 experimental group (relative to the Experiment 2 control group) cannot be explained by a higher proportion of participants whose LIs were close to category thresholds.

Post-experiment interviews.

Bar graph summaries of interview responses regarding cognitive strategies, emotional state, task difficulty and the simulated fMRI environment can be found in Appendix K. As variance in these factors could influence the CBFV response (Knecht, Deppe, Ringelstein, et al., 1998), I analysed interview responses in an attempt to account for inconsistencies in lateralisation estimates between T1 and T2. Hereafter, participants from the control and experimental groups are labelled as C-*α* and E-*α*, respectively.

Cognitive strategies.

Across both groups, participants made reference to 17 different cognitive strategies used for thinking of words during the WG task (see Figure K1), including: free association, inhibiting rude or embarrassing words, covertly sounding out the letter, generating relatively short or long words, generating words with the same prefix or suffix, rehearsing the order of generated words in preparation for the 'say' period, generating rhyming words or synonyms, generating words initially in a second language other than English, generating semantically related words, visualising the letter or the word spellings, generating a predetermined maximum number of words, generating words in a word story, and various other strategies. For the control group, participants made reference to 12 cognitive strategies used during T1

and 14 cognitive strategies used during T2. For the experimental group, participants made reference to 15 cognitive strategies used during T1 and 12 cognitive strategies used during T2. For T1, most participants in the control group (14/22) made reference to generating semantically related words (e.g., Listing animal names beginning with 'K'), whereas most people in the experimental group made reference to generating words using free association (12/22). For T2, most participants across both groups (control: 16/22; experimental: 18/22) said that they repeated words generated during T1 when performing T2. These results demonstrate considerable individual variability in cognitive strategies, as well as carry-over practice effects from T1 to T2.

Emotional state.

Across both groups, most participants reported feeling relaxed during T1 (control: 15/22; experimental: 16/22) and T2 (control: 20/22; experimental: 15/22; Figure K2). More participants reported feeling anxious during T1 (control: 8/22; experimental: 9/22) than T2 (control: 3/22; experimental: 4/22; see Figure K2). Conversely, more participants reported feeling drowsy during T2 (control: 6/22; experimental: 6/22) compared to T1 (control: 3/22; experimental: 3/22). Others reported feeling bored, uncomfortable, and – in the experimental group only – agitated (4/22) and nauseous (1/22) during T2. These results indicate considerable individual differences in emotional state between T1 and T2.

Perceived task difficulty.

Across both groups, most participants said that the WG task was easy to perform during both T1 (control: 10/22; experimental: 9/22) and T2 (control: 14/22; experimental: 11/22; see Figure K3). Some found the task moderately difficult during T1 (control: 8/22; experimental: 7/22) and T2 (control: 4/22; experimental: 7/22) and others found the task hard during T1 (control: 4/22; experimental: 4/22) and T2 (control: 6/22; experimental: 6/22).

Simulated fMRI environment.

Acoustic noise.

In the experimental group, most participants (14/22) habituated relatively quickly to the noise and felt relaxed despite the persistent, loud beeping (see Figure K4). A few participants (4/22) said that the noise helped them to stay focused on the task. For example, participant E-17 said that the noise "made it easier to let my mind go blank. I found myself thinking less. It filled some kind of space. I found it easier to think of nothing, easier to relax". Participant E-12 said that the noise "was actually helping because it was distracting from this thought in my mind that I have to perform". Other participants reported feeling agitated (5/22), anxious (4/22), less focused (2/22), and feeling nauseous (1/22). Overall, contrary to my expectation, the noise did not seem to bother most participants and for some, it was even helpful for performing the task.

Confined space.

Most participants (15/22) reported feeling relaxed despite lying in a narrow tube with their head restrained in the head coil (see Figure K5). Of these 15 participants, two also reported enjoying the space. For example, participant E-10 said "I don't think the environment mattered to me at all, if I was sitting out here [in the chair] or in there [the mock scanner], in fact I liked the privacy that the tube gave me." Participant E-10 also said that they had no claustrophobia and "loved it inside". Participant E-12 said they were "quite curious. It was an interesting environment". Others reported feeling uncomfortable (7/22), anxious (3/22) and nauseous (1/22). Overall, the confined space did not appear to be stressful to most participants, and for some, it was even enjoyable.

Supine posture.

Finally, most participants reported that lying down made them feel comfortable and drowsy (15/22; see Figure K6). Others felt uncomfortable (5/22), as well as anxious and

nauseous (1/22). In sum, there was considerable individual variability in the cognitive strategies participants used to perform the WG task, emotional state during T1 and T2, perceived WG task difficulty during T1 and T2, and the emotional response to the simulated fMRI environment. These results may help to account for variance in lateralisation estimates between T1 and T2.

Discussion

In this experiment, I investigated the influence of the fMRI and fTCD laboratory environments, which differ in terms of noise, space and posture, on the measurement of language lateralisation. It is possible that stress induced by fMRI acoustic noise and confined space could arouse the sympathetic nervous system, which could, in turn, influence CBFV lateralisation estimates. Furthermore, drowsiness induced by lying supine could arouse the parasympathetic nervous system, which could also influence CBFV lateralisation estimates. Overall, stress and fatigue, triggered by the fMRI environment, could confound the measurement of lateralisation, thereby leading to differences between fMRI and fTCD lateralisation estimates. To test this theory, I measured language lateralisation using fTCD while participants performed the WG task either twice (T1 and T2) in the same fTCD environment (control group), and or once in an fTCD environment (T1) and then in a simulated fMRI environment (T2; experimental group). I also measured state anxiety and conducted post-experiment interviews to account for potential variance in lateralisation estimates between T1 and T2. Relative to the control group, I expected the experimental group to show: (1) an increase in state anxiety between T1 and T2, (2) greater absolute LI change between T1 and T2, (3) poorer LI test-retest reliability between T1 and T2, and (4) poorer stability of categorical lateralisation between T1 and T2.

State anxiety and absolute change in LIs between T1 and T2.

Contrary to the first hypothesis, there was no interaction or main effect of group or time on state anxiety. This is consistent with the interview responses, whereby the experimental group appeared to be equally relaxed as the control group, despite the potential stressors of loud acoustic noise and confined space. Furthermore, participants across both groups reported feeling drowsy during T2, irrespective of posture. Contrary to the second hypothesis, there was no substantial difference in absolute LI change between the control and experimental groups. As such, there may have been no difference between the groups in sympathetic and parasympathetic nervous system arousal and hence, no effect on CBFV lateralisation estimates. Although the fMRI environment did not appear to affect most participants in the experimental group, there were several exceptions: when asked about how the fMRI environment made them feel, five participants made reference to feeling anxious. The two cases where the fMRI environment triggered the most extreme anxiety (as determined by interview responses) will be discussed in detail below.

Case 1: participant E-9.

Participant E-9 found the fMRI environment particularly stressful. During T1, she felt "nervous at first, I wanted to do well. But as time went on, I felt more calm and at ease". During T2, she felt "ok for the first few minutes, and then as time went on, I started feeling a bit sick and I felt nauseous". She found the WG task easy during T1, yet relatively difficult during T2. Regarding the noise and space, she said "it made me feel panicky…like my space was getting smaller...the noise mostly made me feel claustrophobic. It was like drilling into my head". Regarding lying supine, she said: "before I started to feel sick, I felt drowsy and I wanted to sleep". In the final trial of T2, she flicked the duress light switch to signal that she wanted to stop the experiment. Despite her heightened anxiety during T2, her STAI scores for T1 and T2 (27 and 29, respectively) were both below the experimental (M_{T1} = 31.00; M_{T2}

= 30.77) and control (M_{T1} = 31.95; M_{T2} = 34.09) group means. This may reflect a social desirability bias inherent to self-report measures. Notably, her language lateralisation estimates appeared to be unaffected by the environment-induced stress. Her LIs were 2.42 and 2.22 for T1 and T2, respectively, with an absolute change of 0.2 points. She was categorised as left lateralised for both T1 and T2. This case conflicts with the idea that stress and drowsiness triggered by the fMRI environment may confound the measurement of lateralisation.

Case 2: participant E-8.

Participant E-8 also found the fMRI simulation stressful, albeit less so than participant E-9. During T1, she felt "chilled, normal…a bit bored" because the task was "kind of repetitive". During T2, she said: " I was trying to sing a song in my head because I was just constantly annoyed…not relaxed…very tired". She found the WG task easy during T1 yet "difficult to stay concentrated and keep on track" during T2. Regarding the noise, she felt "annoyed, anxious to get out". Regarding the space, she was "not claustrophobic but did have a scratch….and that was annoying". Regarding lying supine, she felt "very tired" and "uncomfortable". Her LIs for T1 and T2 were 3.85 and 1.99, respectively, with an absolute change of 1.86 points. This suggests that her LIs shifted in the direction of bilateral activation between T1 and T2, which is consistent with the idea that stress induced by performing a cognitive task in a noisy, claustrophobic environment may put pressure on cognitive resources, leading to compensatory bilateral activation. However her absolute LI change score (1.86) was below the experimental group mean (2.92) and she was categorised as left lateralised for both T1 and T2.

In sum, these two cases suggest that lateralisation estimates are relatively robust to environment-induced stress. However, while most participants' lateralisation estimates remained consistent between T1 and T2, regardless of the laboratory environment in which

they were measured, several individuals showed poor consistency of lateralisation estimates between T1 and T2, particularly in the experimental group. These cases will be explored in the following section.

Consistency of LIs and categorical lateralisation between T1 and T2.

Consistent with the third and fourth hypotheses, the experimental group showed considerably poorer LI test-retest reliability, as well as poorer stability of categorical lateralisation relative to the control group. The poor LI test-retest reliability in the experimental group appears to be driven by several individuals, whose LIs shifted from positive to negative between T1 and T2, or vice versa. This is consistent with categorical lateralisation estimates, whereby eight of 22 (36.4%) participants in the experimental group switched lateralisation categories between T1 and T2, compared to two of 22 (9.1%) participants in the control group (see Table 9 for a summary of the data for these ten individuals). Several factors might account for the change in categorical lateralisation in these ten individuals, including state anxiety, noise, space, posture and other personal characteristics.

Table 9

Summary of the Data (Handedness, State Anxiety and Language Lateralisation) for Participants Whose Categorical Lateralisation Switched Between the Two Repetitions (T1 and T2) of the Word Generation Task, Experiment 2

		STAI		LI			CatLat	
ID	Hand	T1	T2	T1	T2	Change	T1	T2
Control								
8	R	44	43	3.26	0.44	2.82	L	B
17	R	40	36	3.29	-4.77	8.06	L	R
Experimental								
1	**R**	**28**	**28**	**2.65**	**1.94**	**0.71**	**L**	**B**
2	R	20	20	4.57	-2.14	6.71	L	B
5	L	43	36	-3.24	8.72	11.96	R	L
10	L	37	39	2.32	1.78	0.54	L	B
12	**R**	**37**	**25**	**-1.33**	**2.13**	**3.46**	**B**	**L**
14	R	33	27	1.91	0.66	1.25	L	B
15	R	35	49	0.92	1.76	0.84	B	L
21	R	24	23	7.75	-0.86	8.61	L	B

Note. Participants with above group-average STAI (State-Trait Anxiety Inventory) scores for both Time1 (T1) and Time2 (T2) are highlighted in grey. Bilingual participants are in boldface. ID = Participant number. Hand = self-report handedness; LI = lateralisation index; Change = absolute change in LIs between T1 and T2; CatLat = Categorical lateralisation (i.e., left [L], bilateral [B] and right [R]).

Regarding state anxiety, five of the 10 participants whose categorical lateralisation estimates changed between T1 and T2 had above group-average STAI scores for both T1 and T2 (C-8 and C-17; E: 5, 10 and 15). Of note, participant E-5's high state anxiety coincided with the greatest amount absolute LI change (11.96) across both groups. Furthermore, two participants (E-12 and 14) had above average STAI scores for T1 but below average STAI scores for T2. In contrast, three participants (E: 1, 2 and 21) had below average STAI scores at both T1 and T2. Of these, participant E-2 had the minimum STAI scores for T1 (20) and T2 (20) across both groups. Therefore, it is possible that, for some participants, high state

anxiety could lead to poorer consistency of lateralisation indices. However, this cannot account for all cases of poor stability of categorical lateralisation.

Regarding noise, four participants (E: 1, 2, 5 and 21) reported that they felt relaxed despite the noise and habituated quickly. Two other participants (E-10 and E-12) reported that the noise helped them to concentrate better on the task, and eventually they too habituated. In contrast, one participant (E-15) said that the noise made her feel anxious, and that the WG task at T2 was "harder to do…I was very distracted...a bit on edge, I think it was the sound". Another participant (E-14) said that the noise made him feel "confused…because you kept forgetting words but it wasn't anything bad. Relaxing but it was like 'damn, what was that word?'". He also said that occasionally "I'd just be blank and I wouldn't say anything. It was kind of harder to think of words. You'd think of it but forget it straight away…[I] missed about three or four trials". Therefore, for some participants, it is possible that noise interferes with task performance, resulting in poor stability of lateralisation.

Regarding the confined space, five participants (E: 2, 5, 10, 12 and 21) mentioned that they were not bothered by the tube and head coil and felt relaxed. Of these participants, two (E-10 and E-12) also said that they enjoyed the tube environment. Three participants (E: 1, 14 and 15) mentioned feeling uncomfortable. Participant E-1 said that it was "not claustrophobic, but uncomfortable because you can't move…you feel…scratchy." Participant E-14 said the space was "a bit restraining", and participant E-15 said that the head coil was particularly uncomfortable. Therefore, for some individuals, feeling uncomfortable may have led to unstable lateralisation estimates.

Regarding posture, seven participants (E: 2, 5, 10, 12, 14, 15 and 21) reported that lying supine made them feel relaxed and/or drowsy. Participant E-1 said that lying down was fine except that "you can't move, you can't fidget", which suggests that he was not entirely at

ease. Overall, there appeared to be nothing distinctive about these participants' responses to lying supine that might explain their categorical lateralisation switching.

Regarding other personal characteristics, two participants (E-5 and E-10) were self-reported left-handers, and two participants (E-1 and E-12) were bilingual, with English as their second language. Finally, two participants in the experimental group (E-1 and E-10) and two participants in the control group (C-8 and C-17) said that the fTCD headset caused head pain. In sum, there appears to be no common factor that can account for all cases where categorical lateralisation switched between T1 and T2. It is possible that various environment-related factors (e.g., state anxiety, noise, confined space and posture) as well as factors unrelated to the environment (e.g., handedness, bilingualism, and head pain) might influence lateralisation estimates on a case-by-case basis.

Limitations and future directions.

To improve our understanding of how the laboratory environment may influence lateralisation estimates, future research should be guided by several recommendations outlined in the following section.

States vs. personality traits.

Of all factors explored in the previous section, above-average state anxiety was able to account for the highest proportion (50%) of categorical lateralisation 'switchers' across the two groups. It is possible that more stable personality characteristics, such as trait anxiety or introversion, may better account inconsistent lateralisation. Indeed, psychological profiling has found that introverts show increased arousal when subjected to low-level noise relative to extroverts (Standing, Lynn, & Moxness, 1990). Thus, future studies could administer the full state-trait anxiety inventory (instead of only the state portion), as well as a personality measure (e.g., the Revised NEO Personality Inventory; Costa & MacCrae, 1992) to

investigate whether any effect of the laboratory environment on cerebral blood flow is mediated by personality traits.

Teasing apart noise, space and posture.

As I tested all three fMRI environmental factors (i.e., noise, confined space, and supine posture) simultaneously, the extent to which each factor might individually influence lateralisation estimates is unknown. Therefore, future studies could tease apart these factors by assessing each factor separately, or in various combinations. If fMRI acoustic noise is found to influence lateralisation, future fMRI studies may benefit from implementing protocols that minimise noise interference during fMRI assessment, such as fMRI compatible noise-cancelling headphones (e.g., "OptoActive II™ - Features | Optoacoustics," n.d.). Furthermore, if confined space and supine posture are found to influence lateralisation, future fMRI studies may benefit from using open and multi-position MRI scanners in which subjects sit upright and have an unrestricted view in front of them ("Fonar UPRIGHT® MRI," n.d.). However, upright scanners typically employ low magnetic fields and it may be some time before the technology is suitable for functional imaging (Lifshitz et al., 2017).

Categorisation of LIs.

The process of collapsing LIs into categories (i.e., left, bilateral and right) resulted in the systematic loss of measurement information and a concomitant loss of power (Cohen, 1983). Furthermore, while some participants were placed confidently within a category, others were placed on the threshold between categories. As such, a small change in mean LI or standard error could lead to a change in category, which could, in turn, unduly influence categorical lateralisation stability estimates. Given this, it is possible that the high proportion of categorical lateralisation switching between T1 and T2 in the Experiment 1 sample (8/30), as well as in the Experiment 2 experimental group (8/22), may be explained by a high proportion of participants whose LIs were close to the threshold between categories (i.e.,

close to zero). Conversely, the low proportion of categorical lateralisation switching in the Experiment 2 control group (2/22) may be explained by a high proportion of participants whose LIs were strongly lateralised and further from the zero threshold. However, a one-way analysis of variance failed to reject the null hypothesis of no difference between the group means, and a Bayesian ANOVA found substantial evidence for the null hypothesis. Therefore, relative to the Experiment 2 control group, the higher proportion of categorical lateralisation switching in Experiment 1, and in the Experiment 2 experimental group, cannot be explained by a higher proportion of participants whose LIs were close category thresholds.

Experimenter skill.

Alternatively, the high proportion of categorical switching in Experiment 1 may be due to my lack of recent experience in setting up fTCD (i.e., experimenter skill). Consistent with this idea, the Experiment 1 internal consistency for T1 was high (r_s = .80), yet moderate for T2 (r_s = .68). In the three-month interval between Experiment 1 and 2, I gained experience through setting up more than 50 individuals with fTCD. This experience may be reflected in the improved LI internal consistency in Experiment T2 (control group: r_{T1} = .86, r_{T2} = .81; experimental group: r_{T1} = .75, r_{T2} = .81). As such, the high proportion of categorical lateralisation switching may be explained by measurement error in Experiment 1, and the laboratory environment manipulation in Experiment 2.

Experimental design.

A stronger effect of the laboratory environment on language lateralisation estimates may have been masked by several shortcomings of the experimental design regarding the participation eligibility criteria, the fMRI simulation, order effects and the WG task. Firstly, the dearth of participants stressed by the confined space may be the result of an unavoidable selection bias: I requested that individuals not register for my study if they suffered from severe claustrophobia. This criterion may have deterred individuals with even mild

claustrophobia, thereby leading to an overrepresentation of participants who were not prone to claustrophobia. As such, the present study may have underestimated the true effect of the laboratory environment on lateralisation estimates.

Furthermore, there may have been a stronger effect of the fMRI laboratory environment on language lateralisation estimates had the fMRI simulation been more realistic. For example, the simulation did not capture potential pre-assessment stressors, such as being in a hospital setting, having to remove day clothes containing metal (including bras, zippers, buttons, wires and hooks) and changing into hospital scrubs. Furthermore, due to budget restrictions, the tube used to simulate the scanner bore was 100 cm long, which is shorter than most true scanners (e.g., the Macquarie University hospital Siemens 3-T scanner is 173 cm long). Participants could also see the wall of the testing room behind the stimulus laptop screen, which was reflected in the mirror attached to the head coil. In reference to this, one participant mentioned that they felt fine in the tube as the mirror "gives you the impression that you have space". In a true fMRI scanner, participants would not be able to see out of the bore to the testing room – a feature that may increase the rates of claustrophobia during scanning. Future studies could improve the realism of the simulation by asking participants to change into hospital scrubs before the fMRI simulation, extending the length of the tube, and standardising the visual field by draping a sheet behind stimulus laptop screen.

The order in which I tested the two different laboratory environments may have also masked the effect of the laboratory environment on lateralisation. For the experimental group, participants always performed T1 in the fTCD environment, and T2 in the simulated fMRI environment. By comparing the experimental group to the control group, I was able to control for practice and fatigue effects due to almost immediate repetition of the WG task. However, there might have been a stronger effect of the environment had participants in the experimental group performed the WG task in the simulated fMRI environment first. In this

scenario, participants would not have had an hour to acclimatise to experiment, nor would they have had practice on the WG task. As such, the fMRI environment might have been more stressful if it had been administered in T1. To test this possibility, future studies could counterbalance the order of the laboratory environments by including two additional groups: one group where participants perform T1 and T2 in an fMRI environment (i.e., a second control group), and another group where participants perform T1 in an fMRI environment and T2 an fTCD environment (i.e., a second experimental group).

Additionally, conducting T1 right next to the mock scanner gave participants in the experimental group approximately one hour to acclimatise to the tube/head coil mechanism before undergoing the fMRI simulation. Future studies could change testing rooms between T1 and T2 so that participants do not see the mock fMRI scanner until right before they go into it, as would be the case in a true fMRI assessment.

Finally, the study was limited due to the considerable amount of variability in the cognitive strategies participants used to perform the WG task. Across both groups, participants made reference to approximately 17 different cognitive strategies used to perform the WG task. This variability is problematic as it could confound the CBFV response during successive fTCD assessments (Knecht, Deppe, Ringelstein, et al., 1998) and mask an effect of the laboratory environment on language lateralisation estimates. It could also undermine accurate diagnosis when using the WG to assess lateralisation in clinical populations with functional imaging as an alternative to the invasive Wada test. Therefore, future research should work towards developing a cognitive task that better isolates a specific cognitive operation.

General Discussion

The present study was motivated by the fact that previous research has reported imperfect concordance between fMRI and fTCD for the assessment of lateralisation. With

respect to language lateralisation, correlations between fMRI and fTCD have ranged from very high (r = .95; Deppe et al., 2000), high (r_s = .75; Somers et al., 2011) to moderate (r_s = .44; r_s = .49; r_s = .59; Bruckert, 2016). With respect to spatial attention lateralisation, correlations between fMRI and fTCD have ranged from high (r = .69; Jansen et al., 2004), moderate (r_s = .54; Schmidt et al., 1999) to low (r = .34; Hattemer et al., 2011). Several factors may account for discordance between fMRI and fTCD lateralisation estimates, including: (1) variance in the calculation of fMRI lateralisation indices (LIs), (2) variance in individual lateralisation estimates over time, (3) differences between fMRI and fTCD experimental tasks, (4) differences between the fMRI-BOLD and fTCD-CBFV signals and (5) differences between the fMRI and fTCD laboratory environments. The present study investigated the last of these several potential confounds; specifically, whether the fMRI and fTCD laboratory environments, which differ in terms of noise, space and posture, differentially influence the measurement of language lateralisation. I suggested that stress induced by fMRI acoustic noise and confined space, as well as fatigue induced by lying supine, may alter the cerebral blood flow response, thereby leading to differences between fMRI and fTCD lateralisation estimates. Across two experiments, fTCD was used to measure CBFV while participants performed the WG task either twice in an fTCD environment (Experiments 1 and 2), or once in an fTCD environment and then in a simulated fMRI environment (Experiment 2).

In Experiment 1, I investigated the consistency of language lateralisation when participants performed both T1 and T2 in the same fTCD environment. This served as an exploratory experiment to determine the most appropriate research design to incorporate in Experiment 2. A Bayesian analysis indicated anecdotal evidence of no difference between T1 and T2 LIs (BF_{10} = 0.16). Unexpectedly, I found only moderate LI test-retest reliability (r_s = 0.63, p < .001) and poor stability of categorical lateralisation: eight of 30 (26.7) participants

switched categorical lateralisation between T1 and T2. The poor consistency in lateralisation estimates may be due to variance in cognitive strategies, emotional states and task difficulty between the two tasks. These factors could lead to systematic, and possibly unihemispheric, changes in the CBFV response over successive fTCD assessments (Knecht, Deppe, Ringelstein, et al., 1998). I sought to account for these potential sources of variability in Experiment 2 through the inclusion of a state anxiety measure, as well as a post-experiment interview, asking participants about their experience of the T1 and T2 tasks.

In Experiment 2, I compared change in language lateralisation estimates between participants who performed both T1 and T2 in an fTCD environment (control group; as in Experiment 1) and participants who performed T1 in an fTCD environment and T2 in a simulated fMRI environment (experimental group). A Bayesian analysis revealed no difference in absolute LI change between the two groups. However, LI test-retest reliability was considerably lower in the experimental group (r = -.23, p = .331) relative to the control group (r = .80, p < .001). The low correlation may have been driven by several individuals, whose LIs shifted from positive to negative between T1 and T2, or vice versa. Consistent with this, eight of 22 (36.4%) participants in the experimental group switched categorical lateralisation between T1 and T2 compared to two of 22 (9.1%) participants in the control group. Overall, while most lateralisation estimates were robust to the change in the laboratory environment, there were several exceptions where consistency of lateralisation estimates was poor. This suggests that the laboratory environment may partially account for the discordance between fMRI and fTCD lateralisation estimates. Until the laboratory environment confound is eliminated, it remains unclear as to which of the two techniques is most valid for assessing lateralisation. Given the potential confound of the laboratory environment, as well as the several other confounds mentioned above, it seems that fMRI and fTCD are not yet at the

stage where they can be used interchangeably to assess lateralisation, as previously suggested (Deppe et al., 2000).

Conclusion

This is the first study to demonstrate that the laboratory environment is one of many potential confounds that influences the measurement of hemispheric lateralisation. To further our understanding of hemispheric lateralisation, future research should embrace new technologies that help to reduce the interference of the laboratory environment, such as noise-cancelling headphones and open, multi-postural fMRI. Certainly, we need to improve the validity of fMRI and fTCD before they can be used as non-invasive alternatives to the gold standard Wada test for assessing hemispheric lateralisation in patient populations (Binder et al., 1996; Knecht, Deppe, Ebner, et al., 1998). While we will always be constrained by the tools that we use to measure brain function, we can strengthen the validity of these tools through identifying and working towards eliminating their methodological confounds.

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Appendix A

Edinburgh Handedness Inventory (EHI)

Please indicate your preferences in the use of hands in the following activities *by putting + in the appropriate column.* Where the preference is so strong that you would never try to use the other hand unless absolutely forced to, *put ++.* If in any case you are really indifferent *put + in both columns.*

Some of the activities require both hands. In these cases the part of the task, or object, for which hand preference is wanted is indicated in brackets.

Please try to answer all the questions, and only leave a blank if you have no experience at all of the object or task.

		LEFT	RIGHT
1	Writing		
2	Drawing		
3	Throwing		
4	Scissors		
5	Toothbrush		
6	Knife (without fork)		
7	Spoon		
8	Broom (upper hand)		
9	Striking Match (match)		
10	Opening box (lid)		
i	Which foot do you prefer to kick with?		
ii	Which eye do you use when using only one?		

L.Q.		Leave these spaces blank	DECILE	

Appendix B

Flinders Handedness Survey (FLANDERS)

The ten questions below ask which hand you prefer to use in a number of different situations. Please tick one box for each question, indicating whether you prefer to use the left-hand, either-hand, or the right-hand for that task. Only tick the 'either' box if one hand is truly no better than the other. Please answer all questions, and even if you have had little experience in a particular task, try imagining doing that task and select a response.

		Left	Either	Right
1	With which hand do you write?			
2	In which hand do you prefer to use a spoon when eating?			
3	In which hand do you prefer to hold a toothbrush when cleaning your teeth?			
4	In which hand do you hold a match when you strike it?			
5	In which hand do you prefer to hold the rubber when erasing a pencil mark?			
6	In which hand do you hold the needle when you are sewing?			
7	When buttering bread, which hand holds the knife?			
8	In which hand do you hold a hammer?			
9	In which hand do you hold the peeler when peeling an apple?			
10	Which hand do you use to draw?			

Handedness score (please don't fill this out)	

Appendix C

Explanation of the Bayesian Analysis Used in the Present Study

To assess whether there was a difference between LIs for T1 and T2, we used a two-sided, repeated-measures Wilcoxon signed-rank test. However, a potential null result would be impossible to interpret using frequentist statistics. A non-significant result can indicate either: 1) that there is evidence for the null hypothesis or 2) that the data were insensitive to detect an effect (Dienes, 2014). A shortcoming of frequentist statistics is that one cannot distinguish between these two alternatives and therefore, no conclusion follows. The Bayesian approach overcomes this shortcoming as it allows one to distinguish between evidence for the alternative, evidence for the null and insensitive data. Therefore, in order to interpret a potential non-significant result, we used a two-sided, repeated-measures Bayesian Wilcoxon signed-rank test (van Doorn et al., in preparation), assessing whether there was a difference between LIs for T1 and T2. The test does not assume normality and is robust with respect to outliers.

Bayesian statistics quantifies how strongly the data support one theory (e.g., the alternative hypothesis) over another (e.g., the null hypothesis). This is determined via the Bayes factor (*BF*) ratio, which compares the probability of the data fitting under the alternative hypothesis to the probability of the data fitting under the null:

$$BF_{10} = \frac{\text{Probability of observed data under the alternative hypothesis}}{\text{Probability of the observed data under the null hypothesis}}$$

The hypothesis that best predicts the data is preferable. BF_{10} comparing the alternative to the null hypothesis indicates that the data are *BF* times more likely under the alternative. *BF* ranges from zero to infinity. If BF_{10} is greater than 1, the data support the alternative over the null. If BF_{10} is less than 1, the data support the null over the alternative. If BF_{10} is equal to 1, the data are equally well predicted by the alternative and null hypotheses and are therefore insensitive. Conventional cut-offs suggest that a BF_{10} of 3 or more can be taken as substantial

evidence for the alternative, a BF_{10} of 1/3 or less as substantial evidence for the null, and a BF_{10} between 1/3 and 3 as anecdotal evidence (Jeffreys, 1939). However, as the Bayes factor is an odds ratio, it represents continuous evidence and can be reported without reference to cut-offs (Rouder, Speckman, Sun, Morey, & Iverson, 2009).

The Bayes factor requires two types of inputs: 1) a summary of the data and 2) a specification of what the null and alternative hypotheses predict. These predictions must be determined prior to the data analysis and are therefore known as a 'priors'. Priors can be defined in terms of the expected effect size ($\delta = \mu/\sigma$, the population version of the sample Cohen's d; Rouder et al., 2009). For the null hypothesis of no effect, the prior can be defined as a single value ($\delta = 0$). For the alternative hypothesis, the researcher must specify what range of effect sizes are consistent with the theory and if any are particularly likely. The alternative hypothesis prior can be represented by a distribution with its peak centred on the most likely effect size. For the current study, we represented the alternative prior using a Cauchy distribution (a *t* distribution with one degree of freedom, similar to the normal distribution with fatter tails) centred on zero. This is a popular approach advocated for by Jeffreys (1939). For a non-directional hypothesis, the Cauchy distribution predicts both positive and negative effect sizes. For a one-sided test, the folded (or truncated) Cauchy distribution predicts effect sizes either positive or negative effect sizes only.

The width of the Cauchy prior distribution can be varied using the scale parameter *r* (Rouder et al., 2009). Increasing or decreasing the width of the distribution, centred on zero, will scale the distribution to represent smaller or larger effect sizes, respectively. The subjective Bayes school of thought recommends that the prior distribution be determined by the researcher's *a priori* expectations about the effect size, which are informed by the theoretical and experimental context. However, the use of subjective (or informed) priors comes at the risk that the informed prediction is erroneous, overconfident, underestimated

and so on. Hence, the objective Bayes school of thought recommends that the distribution should reflect as few assumptions as possible. If the researcher has no prior knowledge of the expected effect size or do not wish to commit to any effect size estimate, objective Bayes advocates for using a non-informative default prior which can be used across a wide range of scenarios. A number of default priors have been recommended for conducting Bayesian t-tests with the Cauchy prior centred on zero. For example, Rouder et al. (2009) recommended setting the prior width at a default value $r = 1.0$. However, some believe this distribution is unrealistic as it assigns too much mass to large effect sizes. Consequently, the BayesFactor R-package, developed by Morey and Rouder (2015) recommends using a smaller default value of $r = 0.707$. While there is an element of subjectivity involved in defining the prior, Bayes factors are relatively robust to reasonable variation in priors given a moderate sample size (Rouder et al., 2009). In light of this, the current study defined the alternative hypothesis prior using a default Cauchy distribution centred on zero and with the scale set at $r = 0.707$. This predicts that the most likely effect sizes are near zero, but large effect sizes are also possible.

Appendix D

Summary of Experiment 1 Data

Table D1

Summary of Experiment 1 Data: Demographics, Handedness, Behavioural Performance and Language Lateralisation Estimates

			Handedness				Behavioural		LI			CatLat	
ID	Age	Sex	SR	EHI	FLA	QHP	T1	T2	T1	T2	Change	T1	T2
1	18.9	F	R	100.00	10	0.17	3.76	4.09	0.72	0.77	0.05	B	B
2	19.2	F	R	81.82	10	0.07	3.70	4.09	-2.8	2.88	5.68	R	L
3	18.3	F	L	-100.00	-10	-0.50	4.48	4.43	3.25	5.48	2.23	L	L
4	23.8	F	R	84.62	10	0.31	3.52	3.61	1.99	5.04	3.05	L	L
5	18.1	F	R	100.00	10	0.12	3.61	3.91	3.26	3.4	0.14	L	L
6	17.10	F	R	100.00	8	0.50	3.68	2.96	3.12	3.21	0.09	L	L
7	20.0	F	R	100.00	9	0.50	3.48	3.26	2.72	1.98	0.74	L	L
8	21.10	F	R	100.00	10	0.45	3.70	3.70	3.61	3.97	0.36	L	L
9	18.2	M	L	-83.33	-10	-0.50	3.96	4.04	3.09	1.15	1.94	L	B
10	17.8	F	R	100.00	10	0.50	4.09	4.22	9.19	8.95	0.24	L	L
11	28.10	F	R	100.00	10	0.50	3.22	3.77	3.68	3.95	0.27	L	L
12	18.6	F	R	100.00	10	0.50	3.36	4.04	-1.67	-0.71	0.96	R	B
13	18.0	F	L	-53.85	-10	0.17	2.61	2.57	3.41	3.21	0.2	L	L
14	18.10	F	R	100.00	10	0.50	3.48	3.91	3.58	2.8	0.78	L	L
15	22.5	M	L	-100.00	-10	-0.50	4.14	4.04	-1.57	1.05	2.62	R	B
16	22.0	F	R	52.94	10	0.07	3.87	4.35	2.7	2.1	0.6	L	L
17	19.0	F	R	60.00	8	0.50	3.91	4.00	4.14	4.1	0.04	L	L
18	18.7	F	R	50.00	10	0.50	2.78	3.43	0.87	1.88	1.01	B	L
19	25.5	F	R	100.00	10	0.50	4.00	4.52	5.71	6.24	0.53	L	L
20	19.8	F	R	70.00	9	0.50	3.65	3.70	4.59	3.28	1.31	L	L
21	18.6	M	R	85.71	10	0.50	5.04	5.74	3.04	3.86	0.82	L	L
22	17.10	M	R	89.47	10	0.45	4.09	3.55	3.4	1.93	1.47	L	L
23	19.10	F	R	66.67	10	0.21	3.70	3.13	3.02	4.24	1.22	L	L
24	20.6	F	R	60.00	10	0.50	4.00	3.00	-2.27	1.7	3.97	R	B
25	29.5	M	R	100.00	10	0.07	3.30	3.17	-1.43	1.33	2.76	B	B
26	21.10	F	L	-86.67	-8	-0.50	3.77	3.77	2.91	0.86	2.05	L	B
27	19.7	M	R	85.71	10	0.36	4.13	4.48	2.55	1.12	1.43	L	B
28	18.8	M	R	88.89	10	0.50	3.57	3.78	5.07	4.79	0.28	L	L
29	18.7	F	R	80.00	10	0.31	3.17	2.70	2.68	4.75	2.07	L	L
30	20.4	F	R	88.24	10	0.21	4.00	3.87	4.44	3.54	0.9	L	L

Note. Participants whose categorical lateralisation switched between Time1 (T1) and Time2 (T2) are highlighted in grey. ID = Participant ID; SR = Self-reported handedness (left [L], mixed [M] and right [R]) EHI = Edinburgh Handedness Inventory; FLA = The Flinders Handedness survey (FLANDERS); QHP = Quantification of Hand Preference task; Behavioural = Behavioural performance (number of words reported in the 'say' period); LI = Lateralisation index; Change = Absolute change in LIs between T1 and T2; CatLat = Categorical lateralisation (left [L], bilateral [B] and right [R]).

Appendix E

Bayesian Prior and Posterior Plots for Experiment 1

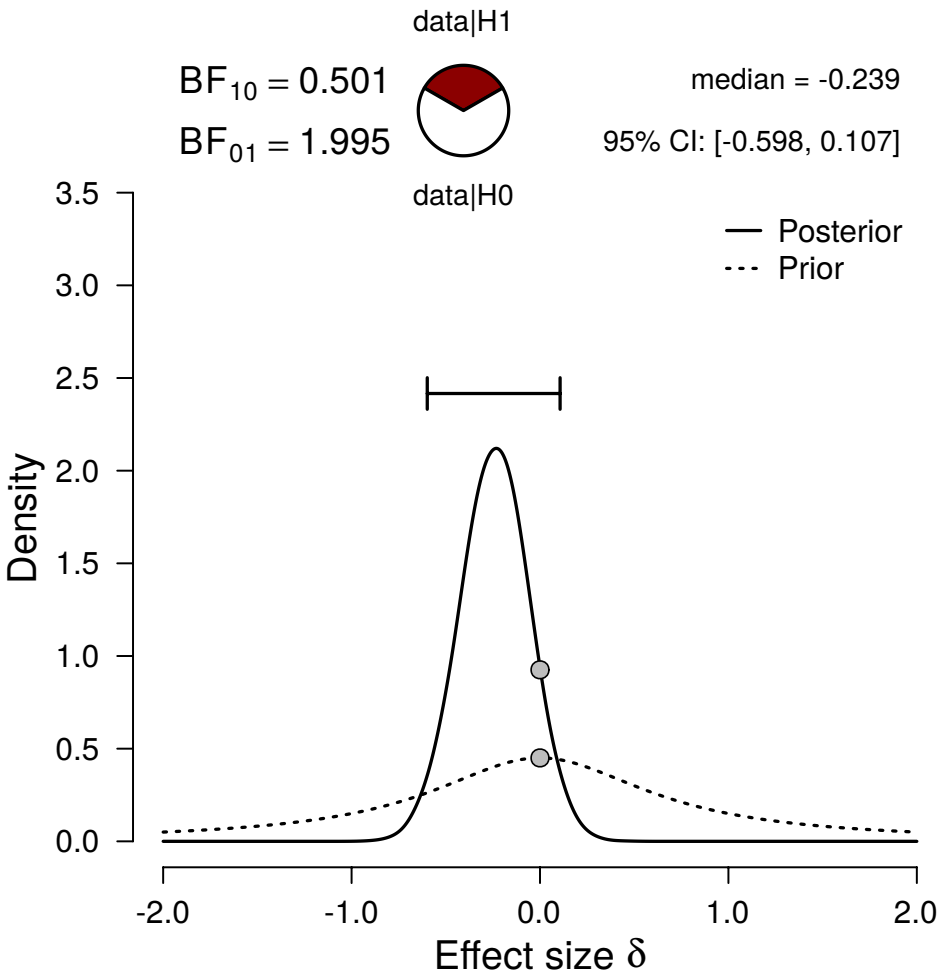

Figure E1. Bayesian prior and posterior plots for Experiment 1 comparison of Time1 (T1) and Time2 (T2) LIs. The prior under the alternative hypothesis (dotted line) is a two-sided default Cauchy distribution centred on zero and with the scale set at r = 0.707. The null hypothesis is not visible but is defined as a single value (δ = 0) – i.e., a spike at zero on the x-axis. The posterior distribution (solid line) represents the best estimate of the population effect size if we were to run the experiment again. The posterior median is -0.239, and 95% of the posterior mass falls between -0.598 and 0.107. The Bayesian analysis compares the prior odds to the posterior odds to see how well the null and alternative hypotheses predict the observed data. The two dots represent the height of the distributions at the null hypothesis of no effect. Here, the Bayes factor supports the null hypothesis.

Appendix F

State-Trait Anxiety Inventory (STAI)

SELF-EVALUATION QUESTIONNAIRE STAI Form Y-1

Please provide the following information:

Name_____Date_____S_____

Age_____ Gender (*Circle*) **M** **F** T_____

DIRECTIONS:

A number of statements which people have used to describe themselves are given below. Read each statement and then circle the appropriate number to the right of the statement to indicate how you feel *right* now, that is, *at this moment*. There are no right or wrong answers. Do not spend too much time on any one statement but give the answer which seems to describe your present feelings best.

	NOT AT ALL	SOMEWHAT	MODERATELY SO	VERY MUCH SO
1. I feel calm	1	2	3	4
2. I feel secure	1	2	3	4
3. I am tense	1	2	3	4
4. I feel strained	1	2	3	4
5. I feel at ease	1	2	3	4
6. I feel upset	1	2	3	4
7. I am presently worrying over possible misfortunes	1	2	3	4
8. I feel satisfied	1	2	3	4
9. I feel frightened	1	2	3	4
10. I feel comfortable	1	2	3	4
11. I feel self-confident	1	2	3	4
12. I feel nervous	1	2	3	4
13. I am jittery	1	2	3	4
14. I feel indecisive	1	2	3	4
15. I am relaxed	1	2	3	4
16. I feel content	1	2	3	4
17. I am worried	1	2	3	4
18. I feel confused	1	2	3	4
19. I feel steady	1	2	3	4
20. I feel pleasant	1	2	3	4

STAIP-AD Test Form Y
www.mindgarden.com

Appendix G

Explanation of the Acoustic Noise Used for the FMRI Simulation

A digital recording of an fMRI echo-planner imaging sequence (sourced from Professor Robert Logie, The University of Edinburgh) was played through a speaker (JBL EON^{TM} Power15, Powered Speaker, JBL Professional, CA, USA) centred 50 cm behind the tube opening. The recording was 4-seconds long and played on a repeating cycle for the duration of the fMRI simulation. As the sound pressure level (*spl*) of fMRI acoustic noise varies between scanners, I chose to replicate the "loud" protocol used in the Tomasi et al. (2005) study: an *spl* of 104 dBA which was measured with an omnidirectional microphone at the entrance of the scanner. Presumably this *spl* was the same at the participant's head inside the head coil. Participants in the Tomasi et al. study wore two levels of ear protection: earplugs (providing an attenuation of 28 dBA) and earmuffs (providing an attenuation of 30 dBA). The combined attenuation would have been approximately 42 dBA and was limited by bone conduction. This level of ear protection is a highly recommended procedure to prevent tinnitus and hearing loss. In the present study, I fitted participants with earplugs (single-use, ER-13-14 3 mm Horn Foam eartips, regular, 13 mm, Etymotic). However, as the earmuffs interfered with the fTCD setup, the *spl* of the original digital recording stimulus was adjusted to emulate the attenuation that would have been provided by wearing both earmuffs and eartips. Figure G1 depicts the power spectrum (21.5 Hz wide frequency bins) and waveforms for the original stimulus (black line, highest in the figure), the stimulus that I presented (blue line, second highest in the figure) and the effective stimulus when playing the stimulus indicated by the blue line whilst wearing eartips (magenta line, lowest in the figure). All of these cases refer to the *spl* inside the scanner at the participant's head with the participant removed.

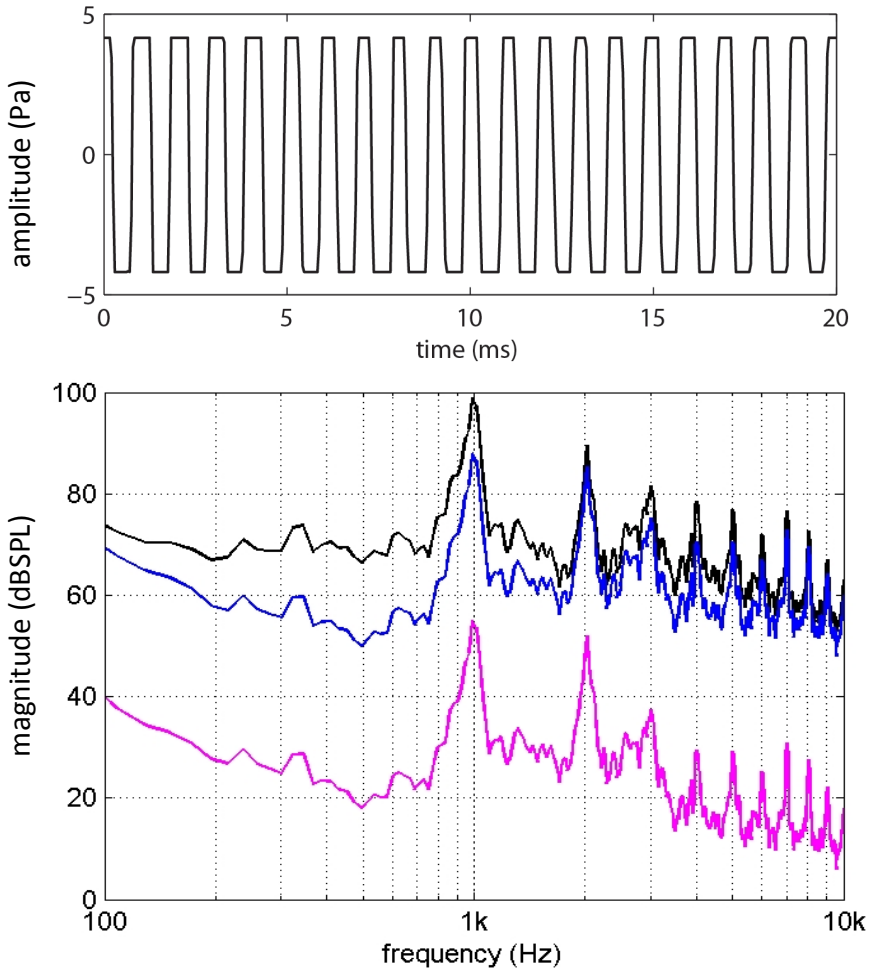

Figure G1. The power spectrum (top panel; 21.5 Hz wide frequency bins) and waveforms (bottom panel) for the original stimulus (black line, highest in the figure), the stimulus that I presented (blue line, second highest in the figure) and the effective stimulus when playing the stimulus indicated by the blue line whilst wearing eartips (magenta line, lowest in the figure). The pulse frequency is slowly decreasing throughout the recording, creating a very slow rate-modulation when looped of less than 0.5 Hz.

Appendix H

Post-Experiment 2 Interview Questions

All participants were asked the following questions:

1. Can you describe your strategy for thinking of words during the first task?
2. Can you describe your strategy for thinking of words during the second task?
3. How did you feel during the first task?
4. How did you feel during the second task?
5. How difficult did you find the first task?
6. How difficult did you find the second task?

Participants assigned to the experimental group, who experienced the simulated fMRI environment, were asked the following additional questions:

7. How did the noise make you feel?
8. How did the space make you feel?
9. How did lying down make you feel?

Appendix I

Summary of Experiment 2 Data

Table I1

Summary of Experiment 2 (Control Group) Data: Demographics, Handedness, State Anxiety, and Language Lateralisation Estimates

			Handedness				STAI		LI			CatLat	
ID	Age	Sex	SR	EHI	FLA	QHP	T1	T2	T1	T2	Change	T1	T2
1	18.7	F	R	60.00	10	0.50	30	24	2.69	1.83	0.86	L	L
2	18.2	F	R	52.94	9	0.50	34	37	2.16	3.26	1.1	L	L
3	28.1	F	R	84.62	9	-0.26	33	35	4.22	4.04	0.18	L	L
4	30.4	M	R	76.47	10	0.02	22	22	-2.01	-2.55	0.54	R	R
5	27.2	F	R	86.67	10	0.17	22	22	1.26	1.48	0.22	L	L
6	18.6	F	R	83.33	10	0.50	25	24	3.83	2.83	1	L	L
7	20.10	F	L	-64.71	-10	-0.02	26	22	0.47	-0.74	1.21	B	B
8	18.7	F	R	69.23	10	0.50	44	43	3.26	0.44	2.82	L	B
9	20.10	M	L	-52.94	-7	-0.50	42	43	-3.38	-8.81	5.43	R	R
10	20.1	M	R	69.23	10	0.12	40	37	8.48	6.67	1.81	L	L
11	31.8	M	R	100.00	10	0.50	29	32	3.05	3.39	0.34	L	L
12	18.11	F	R	63.64	10	0.50	36	32	3.97	6.31	2.34	L	L
13	25.2	F	R	100.00	10	0.02	30	39	2.8	2.57	0.23	L	L
14	51.8	F	R	90.00	10	-0.50	26	31	2.31	2.97	0.66	L	L
15	65.4	M	R	100.00	10	0.31	29	29	-1.63	-4.58	2.95	R	R
16	19.0	F	L	-100.00	-10	-0.50	23	37	2.12	1.87	0.25	L	L
17	18.1	F	R	75.00	10	0.50	40	36	3.29	-4.77	8.06	L	R
18	19.10	F	R	60.00	8	0.45	28	20	1.9	3.93	2.03	L	L
19	22.0	F	R	80.00	8	0.45	37	39	3.79	4.75	0.96	L	L
20	28.3	M	R	68.42	9	-0.40	35	45	2.92	2.73	0.19	L	L
21	19.4	F	R	90.00	9	0.50	29	60	5.92	6.47	0.55	L	L
22	20.0	F	R	90.00	8	0.45	43	41	2.6	4.91	2.31	L	L

Note. Participants whose categorical lateralisation switched between Time1 (T1) and Time2 (T2) are highlighted in grey. ID = Participant ID; SR = Self-reported handedness (left [L], mixed [M] and right [R]) EHI = Edinburgh Handedness Inventory; FLA = The Flinders Handedness survey (FLANDERS); QHP = Quantification of Hand Preference task; STAI = State Trait Anxiety Inventory; LI = Lateralisation index; Change = Absolute change in LIs between T1 and T2; CatLat = Categorical lateralisation (left [L], bilateral [B] and right [R]).

Table I2

Summary of Experiment 2 (Experimental Group) Data: Demographics, Handedness, State Anxiety, and Language Lateralisation Estimates

			Handedness				STAI		LI			CatLat	
ID	Age	Sex	SR	EHI	FLA	QHP	T1	T2	T1	T2	Change	T1	T2
1	28.9	M	R	80.00	9	0.02	28	28	2.65	1.94	0.71	L	B
2	20.7	F	R	100.00	10	0.50	20	20	4.57	-2.14	6.71	L	B
3	34.2	F	R	100.00	10	0.50	29	32	4.13	3.79	0.34	L	L
4	26.6	M	R	78.95	10	0.17	30	23	2.35	6.34	3.99	L	L
5	18.0	F	L	-83.33	-8	-0.36	43	36	-3.24	8.72	11.96	R	L
6	19.0	F	R	100.00	10	0.50	44	35	3.33	4.21	0.88	L	L
7	19.0	F	R	100.00	10	0.50	21	24	2.82	2.61	0.21	L	L
8	18.8	F	R	60.00	9	0.50	24	27	3.85	1.99	1.86	L	L
9	19.0	F	R	60.00	9	0.21	27	29	2.42	2.22	0.2	L	L
10	18.6	F	L	-40.00	-10	-0.02	37	39	2.32	1.78	0.54	L	B
11	33.7	M	R	75.00	10	0.50	36	30	4.13	4.51	0.38	L	L
12	36.3	F	R	100.00	10	0.50	37	25	-1.33	2.13	3.46	B	L
13	30.0	F	R	55.56	9	0.02	41	36	3.13	2.86	0.27	L	L
14	18.7	F	R	100.00	10	0.50	33	27	1.91	0.66	1.25	L	B
15	22.4	F	R	66.67	7	0.12	35	49	0.92	1.76	0.84	B	L
16	21.0	M	R	36.84	10	0.17	29	52	3.08	4.13	1.05	L	L
17	36.5	M	R	87.50	9	0.02	22	26	2.27	5.87	3.6	L	L
18	20.8	M	R	55.56	10	0.50	25	29	3.03	7.36	4.33	L	L
19	22.1	F	R	80.00	10	0.45	34	32	4.08	14.97	10.89	L	L
20	22.0	M	R	85.71	9	0.45	27	24	3.25	4.28	1.03	L	L
21	28.1	F	R	60.00	9	0.02	24	23	7.75	-0.86	8.61	L	B
22	27.5	M	R	33.33	9	-0.07	36	31	3.32	4.36	1.04	L	L

Note. Participants whose categorical lateralisation switched between Time1 (T1) and Time2 (T2) are highlighted in grey. ID = Participant ID; SR = Self-reported handedness (left [L], mixed [M] and right [R]) EHI = Edinburgh Handedness Inventory; FLA = The Flinders Handedness survey (FLANDERS); QHP = Quantification of Hand Preference task; STAI = State Trait Anxiety Inventory; LI = Lateralisation index; Change = Absolute change in LIs between T1 and T2; CatLat = Categorical lateralisation (left [L], bilateral [B] and right [R]).

Appendix J

Bayesian Analysis Plots for Experiment 2

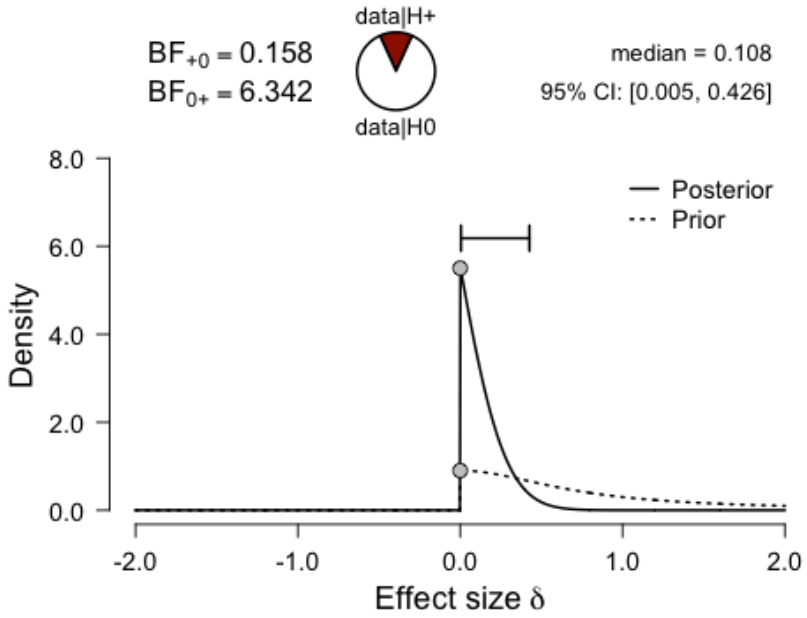

Figure J1. Bayesian prior and posterior plots for Experiment 2. The prior under the alternative hypothesis (dotted line) is a folded Cauchy prior distribution centred on zero with the scale set at a default value of r = 0.707. The null hypothesis is not visible but is defined as a single value (δ = 0) – i.e., a spike at zero on the x-axis. The posterior distribution (solid line) represents the best estimate of the population effect size if we were to run the experiment again. The posterior median is 0.108, and 95% of the posterior mass falls between 0.005 and 0.426. The Bayesian analysis compares the prior odds to the posterior odds to see how well the null and alternative hypotheses predict the observed data. The two dots represent the height of the distributions at the null hypothesis of no effect. Here, the Bayes factor supports the null hypothesis.

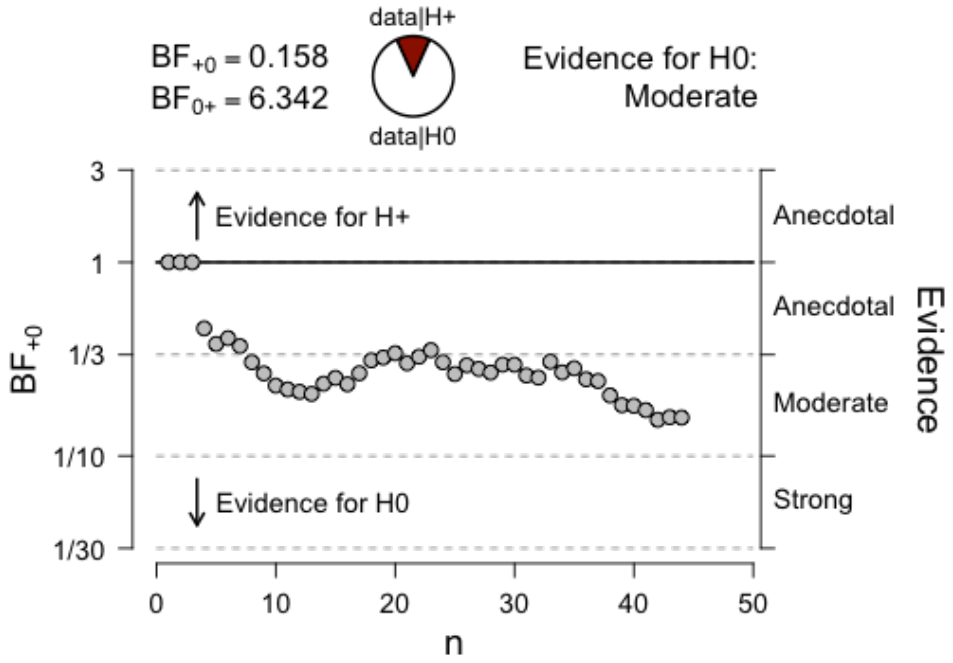

Figure J2. Sequential calculation of the Bayes factor (*BF*) for Experiment 2 for each additional participant, with an overall increase in evidence for the null hypothesis.

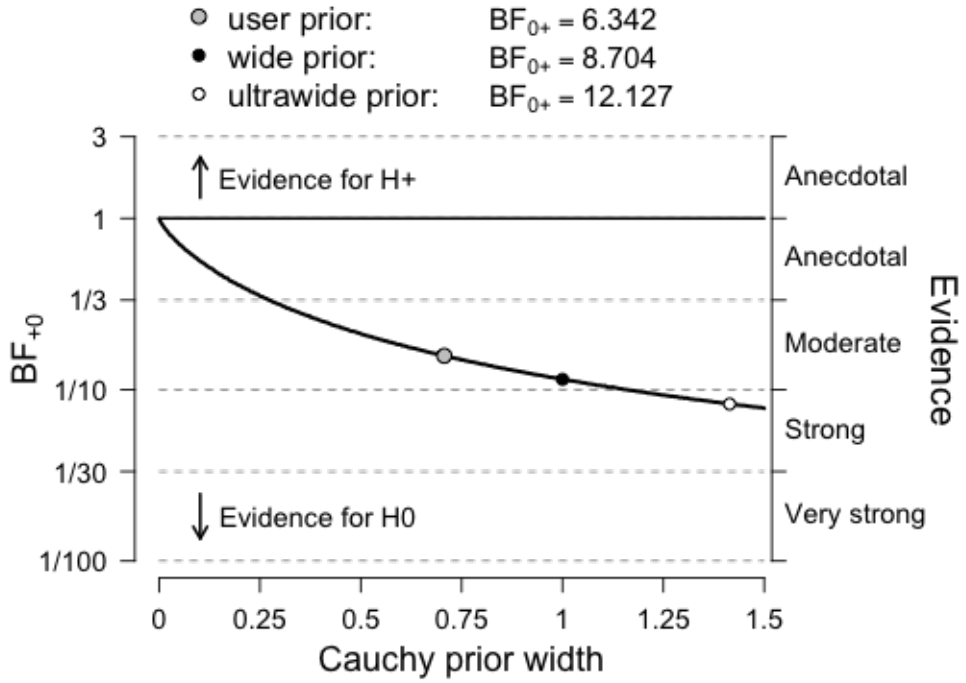

Figure J3. Bayes factor (*BF*) robustness check for Experiment 2. The prior under the alternative hypothesis is a folded Cauchy prior distribution centred on zero. This figure demonstrates that evidence for the null hypothesis is most likely, regardless of the prior width.

Appendix K

Bar Graph Summaries of the Post-Experiment 2 Interview Responses

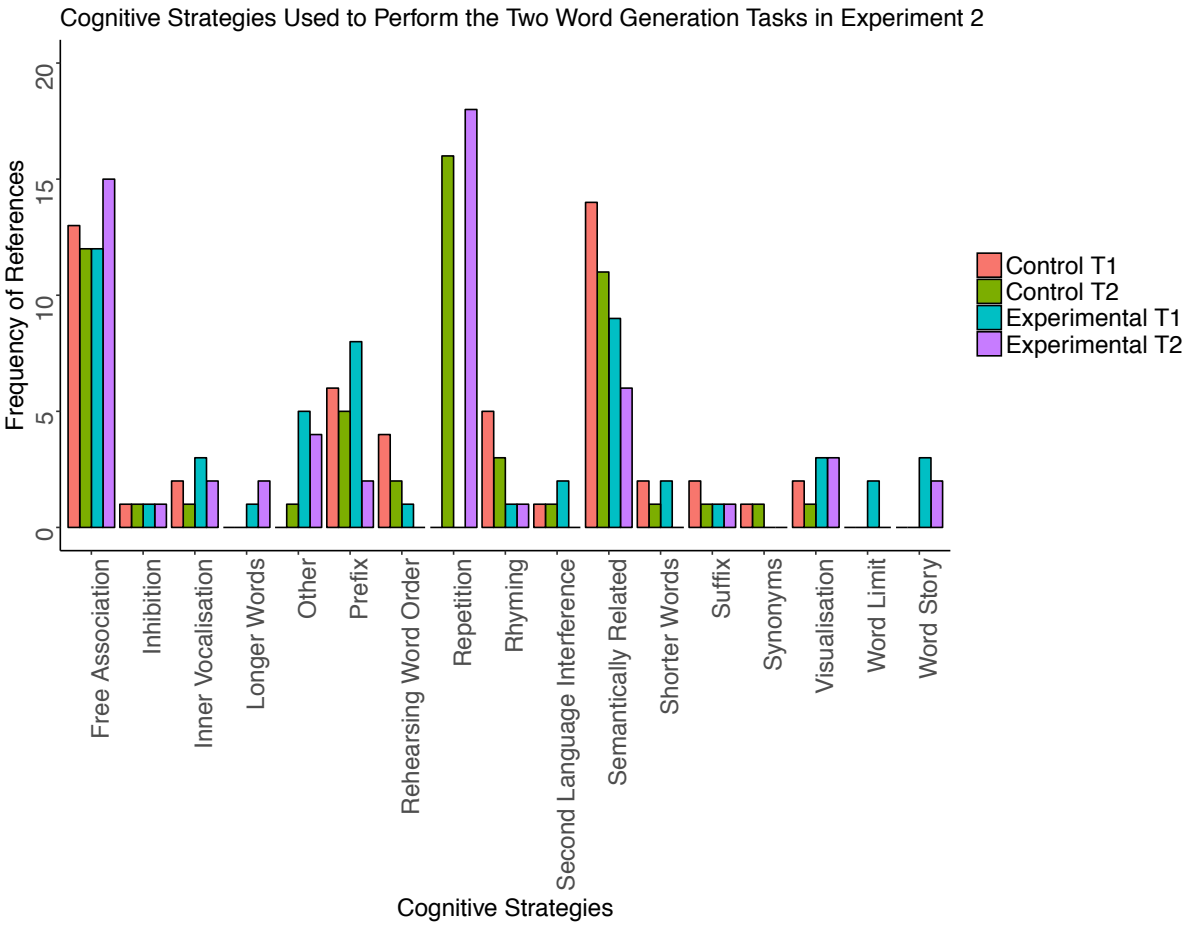

Figure K1. Summary of Experiment 2 interview responses regarding cognitive strategies used to perform the first (Time1 = T1) and second (Time2 = T2) Word Generation tasks, for the control and experimental groups, respectively.

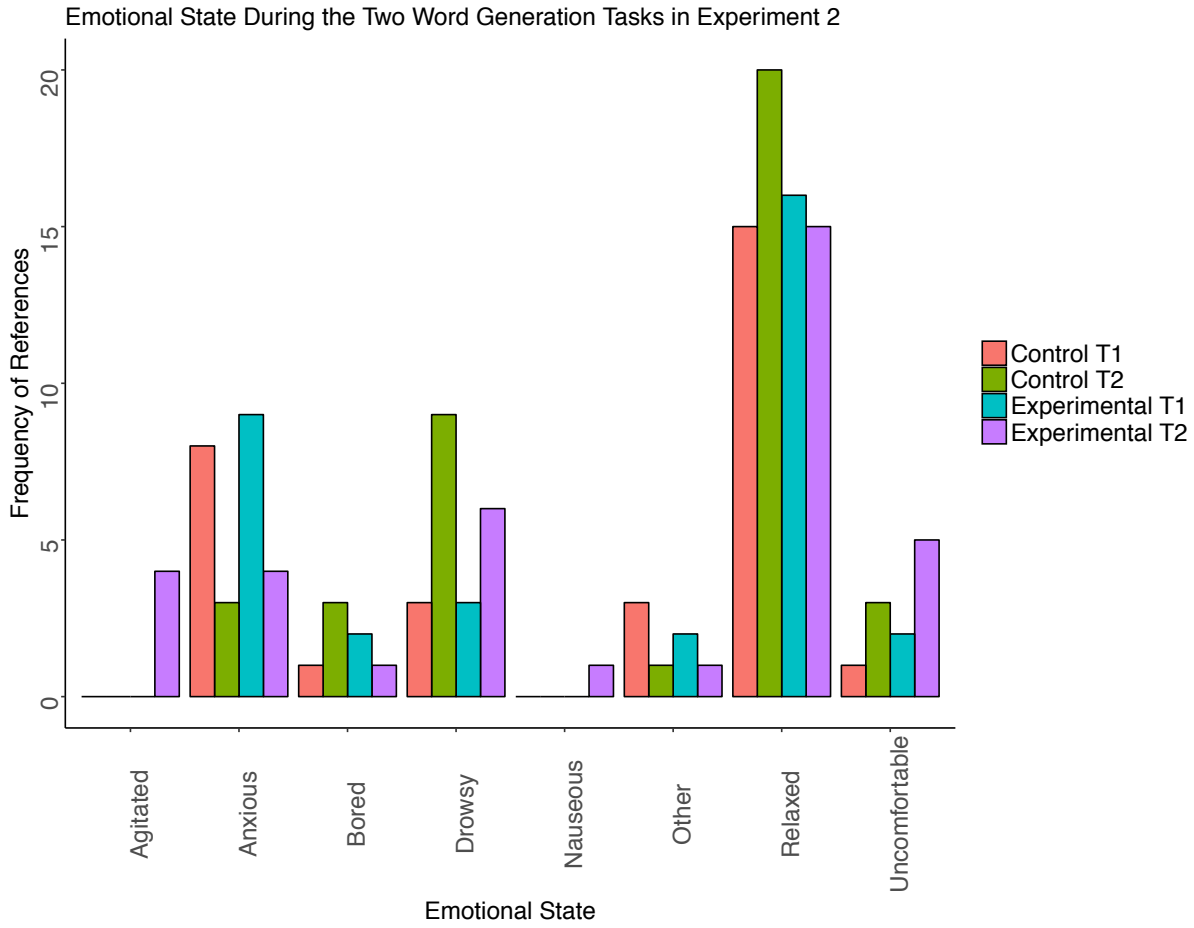

Figure K2. Summary of Experiment 2 interview responses regarding how participants felt during the first (Time1 = T1) and second (Time2 = T2) Word Generation tasks, for the control and experimental groups, respectively.

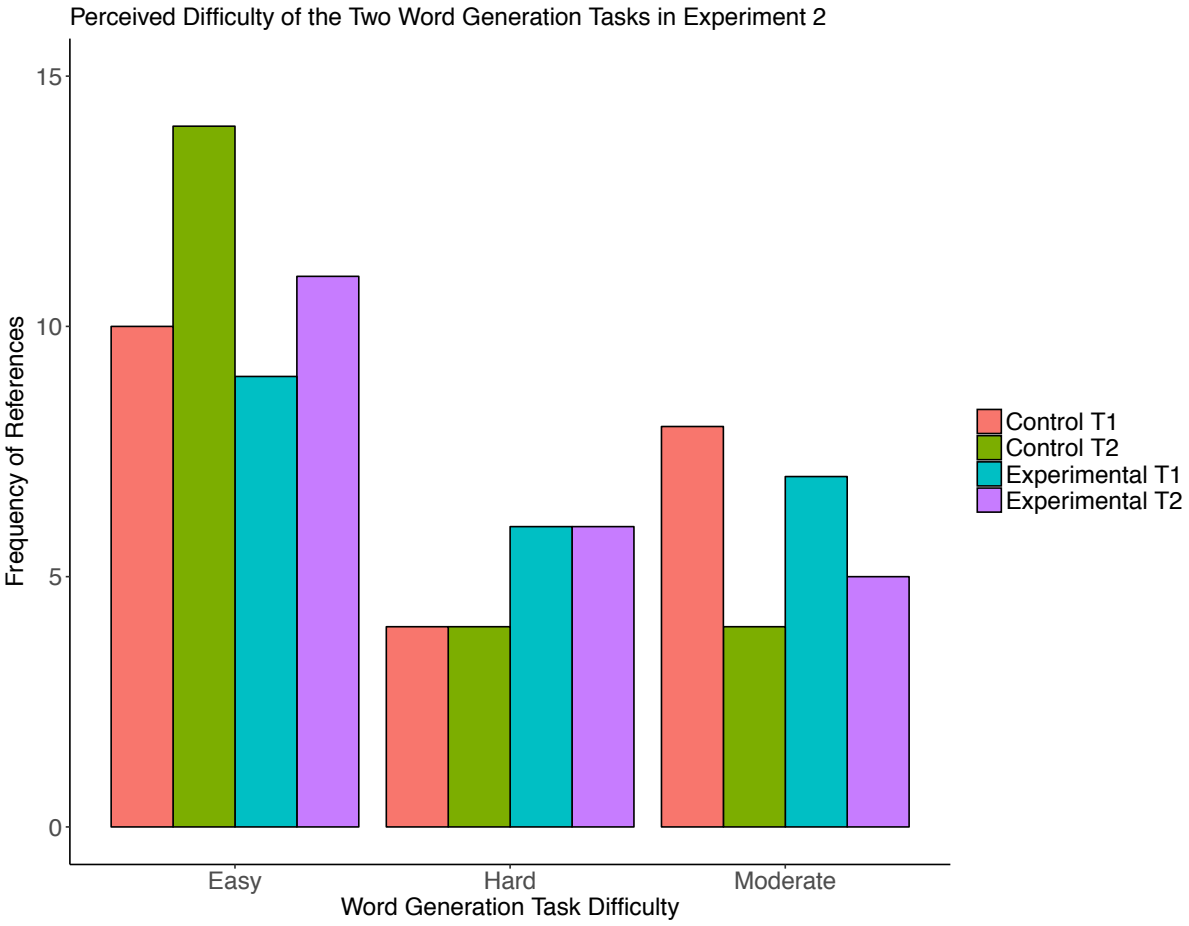

Figure K3. Summary of Experiment 2 interview responses regarding how difficult participants found the first (Time1 = T1) and second (Time2 = T2) Word Generation tasks, for the control and experimental groups, respectively.

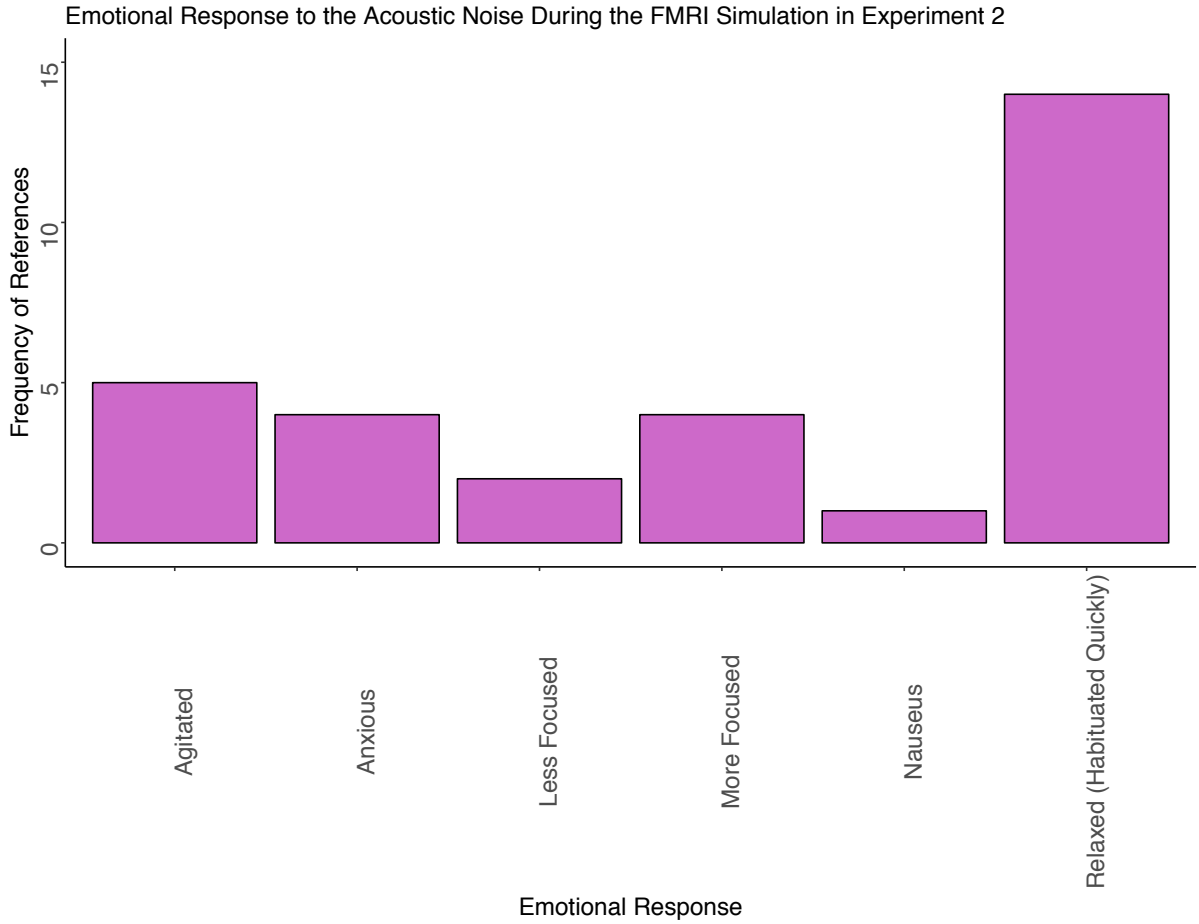

Figure K4. Summary of Experiment 2 (experimental group) interview responses regarding how the acoustic noise of the fMRI simulation made them feel.

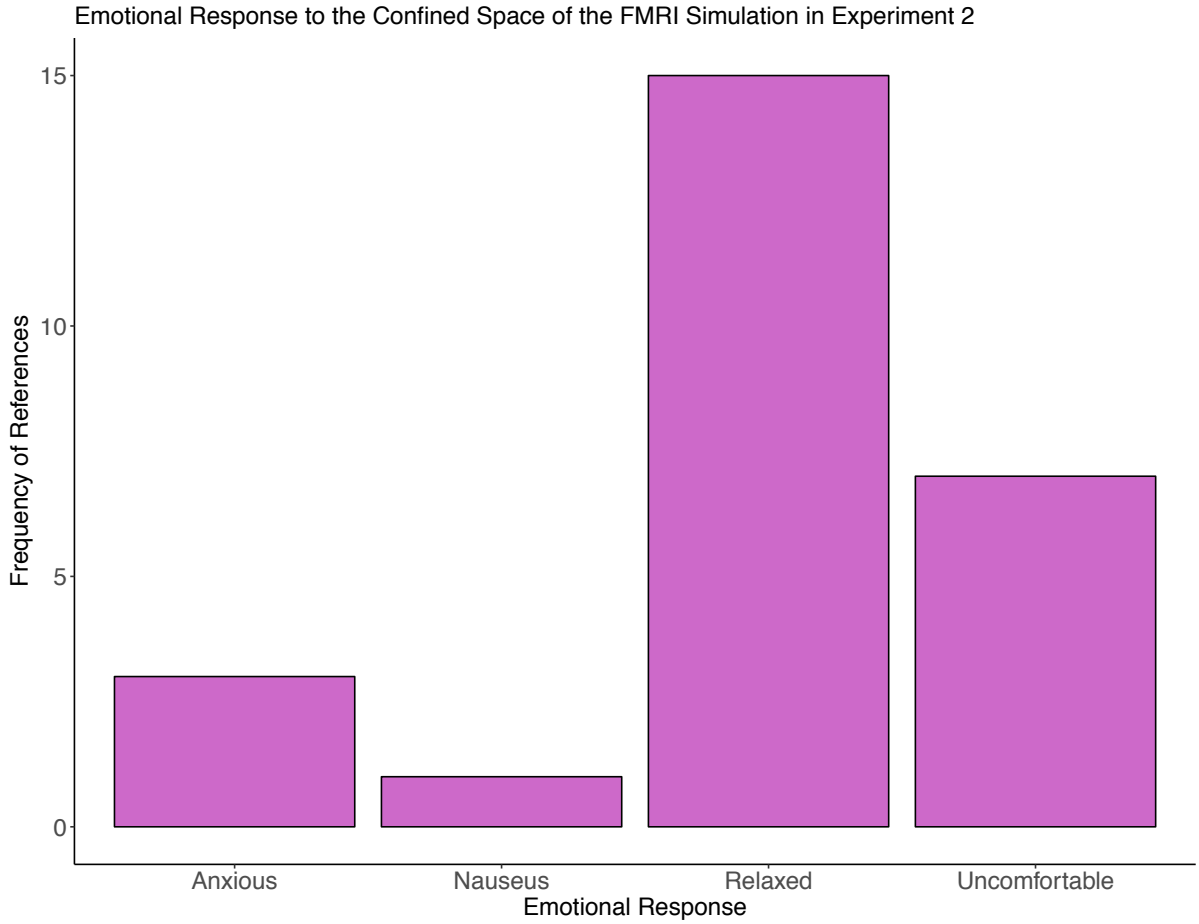

Figure K5. Summary of Experiment 2 (experimental group) interview responses regarding the confined space (i.e., the tube and the head coil) of the fMRI simulation made them feel.

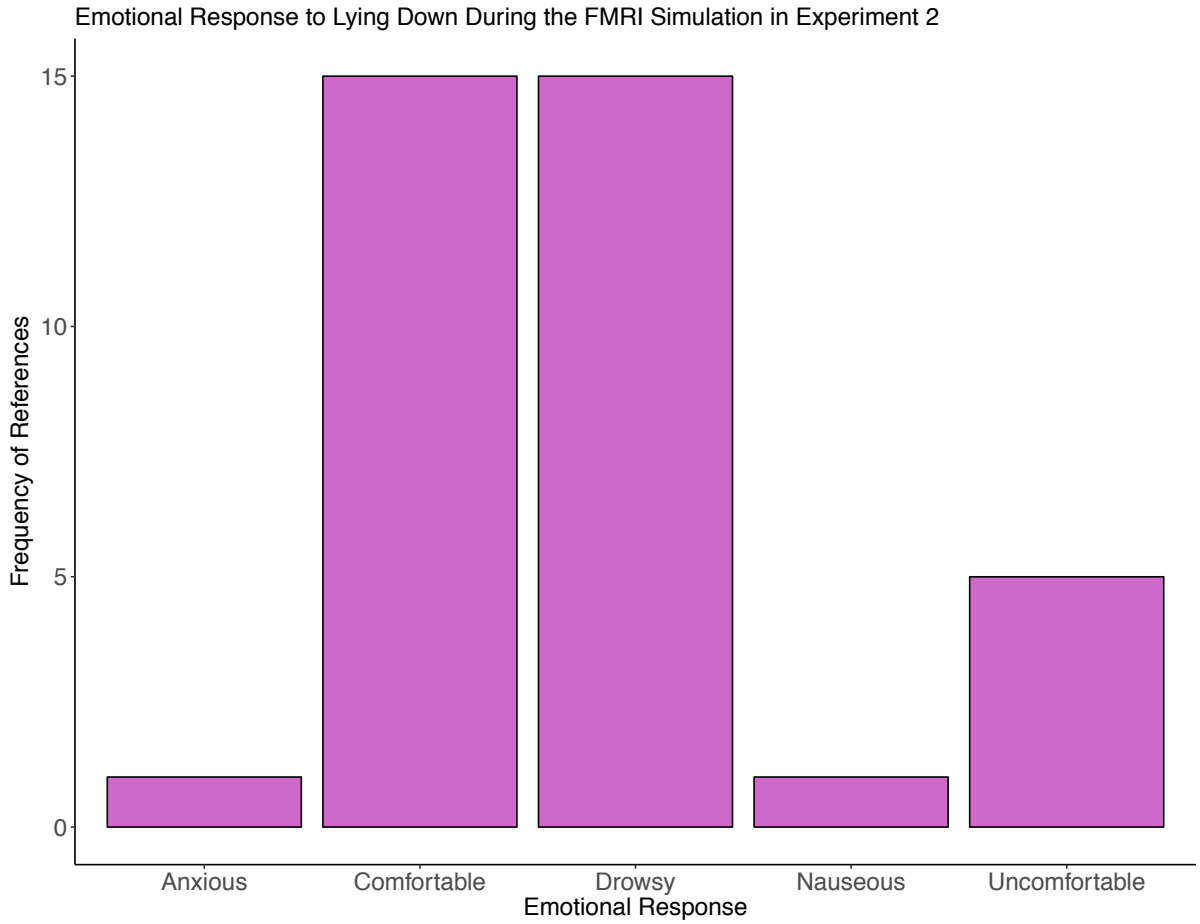

Figure K6. Summary of Experiment 2 (experimental group) interview responses regarding how lying supine during the fMRI simulation made them feel.

APPROVED
By Rebeka Tennent at 12:35 pm, Apr 12, 2017

Human Research Ethics Committee

REQUEST FOR AMENDMENT FORM

Please complete this form for all amendments/modifications including extensions to approved ethics projects.

For quick and efficient review of your amendment, please provide sufficient information in this document to allow the amendment to be reviewed as a standalone document (i.e. it does not require the Ethics Secretariat or HREC reviewing the original application).

Please attach tracked and clean copies of all amended documents to the amendment request. Documents could include participant information and consent forms (PICF), advertising material, surveys, interview questions, verbal scripts, support letters from external organizations.

Submitting this form:

HREC approved applications: Please send this form to ethics.secretariat@mq.edu.au.

Faculty/School-approved applications:
Please send this form to the ethics subcommittee administrator of the relevant Faculty/School
Faculty of Human Sciences: fhs.ethics@mq.edu.au
Faculty of Science and Engineering: sci.ethics@mq.edu.au
Faculty of Arts: artsro@mq.edu.au
Faculty of Business and Economics: fbe-ethics@mq.edu.au
MGSM: ethics@mgsm.edu.au
PACE: pace.ethics@mq.edu.au
Faculty of Medicine and Health Sciences: ethics.secretariat@mq.edu.au.

Handwritten forms will not be accepted.

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1. **Human Research Ethics Committee Reference No:** 5201500074

2. **Chief Investigator/Supervisor:** Nicholas Badcock

   Faculty: Human Sciences

   Department: Cognitive Science

   Email: nicholas.badcock@mq.edu.au

   Date of amendment: 10-Mar -2017

3. **Names of Co-Investigators/Associate Supervisors/Research Assistants:** Prof Alberto Avolio, Mr Adam Bentvelzen, Mr Cory Bill, Prof Dorothy Bishop, Dr Isabelle Boisvert, Mrs Ann Carrigan, Mr Nathan Caruana, Ms Leidy Castro-Meneses, Dr Eugene Chekaluk, Dr Kim Curby, Prof Katherine Demuth, Dr Margriet Groen, Dr Eva Gutierrez-Sigut, Ms Jessica Hofmann, A/ Prof Blake Johnson, Dr Hannah Keage, Ms Yvette Kezilas, Mr Giles King, Dr Mark Kohler, Ms Trudy Krajenbrink, Dr Linda Larsen, Dr Mairead MacSweeny, A/Prof Gen McArthur, A/Prof Cath McMahon, Ms Alyssa Mulray, Mr Vishnu Nair, Ms Heather Payne, Ms Hannah Rapaport, A/Prof Greg Savage, Ms Thaatsha Sivananthan, Dr Paul Sowman, Ms Joann Tang, Mr Jordan Wehrman, Dr Alex Woolgar, Dr Ivan Yuen, Mrs Julianne Pascoe, Mr Andrew James, Ms Maia Zucco, Ms Nicola Filardi, Ms Vanessa Dennis, Mrs Trudy Green

   (Note: If the project is to be undertaken by an Honours/postgraduate/HDR student, the supervisor will be considered the Chief Investigator. The student may be named as a co-investigator.)

4. **Project Title:** The lateralization of cognitive functions

5. **Description of the amendment/s:**
   Please clearly explain the changes that have occurred or are intended. Please describe what is currently approved and how the amendment(s) alter this.

The current approval includes the assessment of cognitive lateralization using functional Transcranial Doppler Ultrasound and Electroencephalography in combination with lingual imaging to monitor tongue movements. The approval includes verbal and visually presented words, sentences, and sounds as well as visually present images broadly affording mapping of language and spatial lateralization.

In the current amendment, we wish to include two additional researchers to the protocol and have four new project-specific info-consent forms and advertisements approved. Three of these projects relate to students – honours and MRes. All elements of these studies have been previously approved for research with the proposed undergraduate populations with a valid license (in the case of the driving project). Therefore their combination here does not introduce any risk or changes to the ethical nature of the research.

Project 5-1: The lateralisation of spatial ability (Honours 1)
The aim of this study is to investigate the relationship between the lateralization of spatial ability within the brain and performance on behavioural measures of visuospatial ability. Lateralization of brain function will be measured using the Transcranial Doppler Ultrasound imaging technique. Visual stimuli will be adapted from the landmark paradigm outlined by Rosch, Bishop, and Badcock (2012). On each trial, participants will be presented with a horizontal line bisected either to the right or left of exact middle by a vertical line. The task is to determine whether the bisecting line appears to the right or left, and task difficulty will be manipulated on an individual basis using an adapted staircase procedure.
A selection of tests from the fourth edition of the Wechsler Adult Intelligence Scale (WAIS-IV) will be administered in order to obtain a behavioural measure of spatial ability. Three subtests will be used - Block Design, Visual Puzzles, and Matrix Reasoning. Results from these tests will be used to obtain a Perceptual Reasoning Index which allows for a general description of each participant's visuospatial ability.

Project 5-2: Cognitive Flexibility and Laterality (Honours 2)

This study will examine the relationship between cognitive flexibility and lateralisation (verbal and visuo-spatial). Lateralisation will be assessed using functional Transcranial Doppler Ultrasonography (fTCD), and cognitive flexibility measured by performance on a simulated driving task requiring participants to drive on the opposite side of the road to usual.

Lateralisation will be assessed using the verbal and visuo-spatial paradigms previously described (ie Word Generation for verbal and Landmark for visuo-spatial). Cognitive flexibility will be assessed by a novel driving task in a driving simulator. Participants, who have previously driven only right-hand drive cars on the left-hand side of the road, will be required to complete a short (<10 minutes) driving simulation in a left-hand drive format and on the right-hand side of the road. Making safe turns, avoiding hazards and other measures of safe vs. unsafe driving under a variety of conditions (e.g. rural/urban traffic settings) will be measured. Past research suggests that left/mixed handed participants perform better than strongly right handed participants in tests of cognitive flexibility and psychomotor speed, indicated by their faster task completion times on a switching of attention (letters/numbers) test (Gunstad, Spitznagel, Luyster, Cohen & Paul, 2007). However, handedness is considered a poor proxy for cerebral lateralisation (Groen, Whitehouse, Badcock & Bishop, 2013), therefore a more direct measure will be used in the current study to provide a clear test of the relationship between lateralisation and cognitive flexibility.

Project 5-3: Lab environment and language lateralisation (Masters of Research)

The project builds upon existing research (Somers et al., 2011) demonstrating a difference between language lateralization assessed with functional Transcranial Doppler Ultrasound (fTCD) and functional Magnetic Resonance Imaging (fMRI). In order to determine whether testing environments can account for some of the differences noted, fTCD assessment of language lateralisation (using the Word Generation task) will be conducted in standard and stimulated fMRI environments. In the standard condition, participants will be seated upright in an open and quiet environment. In the fMRI simulated environment, participants will be lying down on a massage table, inside tube (circular bore diameter = 70cm, length = 173 cm; open at both ends of the tube), with their head resting in an fMRI head coil (e.g., pictured to the right), wearing earplugs and headphones. Participants will hear a recording of fMRI scanner noise (104 db). This will be conducted under the supervision of National Acoustics Laboratory in the anechoic chamber of The Australian Hearing Hub.

Project 5-4: The Lateralisation of Cognitive Functions - Crowding (Other)

It is well documented that, on average, verbal and visuo-spatial abilities are lateralized to the left and right hemispheres of the brain respectively (e.g., Rosch et al., 2012). However, it is hotly debated whether the opposite applies to people who are 'atypically' lateralized – that is, verbal abilities in the right hemisphere and visuo-spatial in the right. This project will test this theory by 1) using standard Word Generation and Landmark tasks to assess verbal and visuo-spatial lateralization and 2) selecting a sub-sample of atypically lateralized individuals to complete a further 2-hours of more sensitive verbal and visuo-spatial tasks. These more sensitive tasks involve control conditions with very-low performance difficulty, standardly used in fMRI experiments (e.g., Cai et al., 2013) but not previously used with fTCD. For Word Generation, this typically involves generating words beginning with a presented letter. For the control condition, participants will repeat a single word, therefore activating the same brain regions as word generation, without the effort to generate an original word. For

visuo-spatial, the Landmark task will be used, contrasting a very easy decision with more challenged (ie the vertical line a long way from the centre = easy left or right judgement, versus the vertical line close to the centre = hard judgement).

References

Cai, Q., Haegen, L. V. der, & Brysbaert, M. (2013). Complementary hemispheric specialization for language production and visuospatial attention. *Proceedings of the National Academy of Sciences*, *110*(4), E322–E330. https://doi.org/10.1073/pnas.1212956110

Groen, M. A., Whitehouse, A. J., Badcock, N. A., & Bishop, D. V. (2013). Associations between handedness and cerebral lateralisation for language: a comparison of three measures in children. *PLoS One*, *8*(5), e64876.

Gunstad, J., Spitznagel, M. B., Luyster, F., Cohen, R. A., & Paul, R. H. (2007). Handedness and cognition across the healthy lifespan. *International Journal of Neuroscience*, *117*(4), 477-485.

Rosch, R. E., Bishop, D. V. M., & Badcock, N. A. (2012). Lateralised visual attention is unrelated to language lateralisation, and not influenced by task difficulty – A functional transcranial Doppler study. *Neuropsychologia*, *50*(5), 810–815. https://doi.org/10.1016/j.neuropsychologia.2012.01.015

Somers, M., Neggers, S. F. W., Diederen, K. M., Boks, M. P., Kahn, R. S., & Sommer, I. E. (2011). The measurement of language lateralization with functional transcranial Doppler and functional MRI: a critical evaluation. *Frontiers in Human Neuroscience*, *5*, 31. https://doi.org/10.3389/fnhum.2011.00031

6. Rationale for the amendment(s):

Clearly describe the reason for the changes listed in section 5

The updates relate to three student projects (Penny Kirk, Peta Larkin, and Hannah Rapaport) and one researcher project (Nic Badcock). The latter amendment is to more specifically describe the conditions of participation as the experiment involves multiple steps – all previously approved.

7. Changes to study documents:

Describe what changes have been made to the study documents as a result of the amendment request(s) listed in section 5 (e.g. Consent form, advertisement or protocol).

Please attach tracked (where possible) and clean copies of documents.

The two new researchers' names have been added to the information and consent form, and descriptions added to specific the updated projects.

8. Potential inconveniences or risks to participants:

Please outline any potential inconveniences or risks to participants arising from changes in section 5. Risks include any changes to confidentiality provisions, psychological or physical risks, increased time commitments, etc.

Please explain how you will reduce potential inconveniences and/or risks to participants.

None

9. Expected date of implementation of the amendments:

Date: **[**20/03/2016**]** (dd/mm/yyyy)

10. Adding Research Personnel

Include the below details for new research personnel being added to the study.

Name:	Penny Kirk
Title:	Miss
Personnel type:	☐Staff ← OR → ☒ Student
Staff / Student no.:	43680550
Qualifications:	
Positions held: (if student, specify Faculty, Department, degree and course in which enrolled)	Currently completing a Bachelor of Psychology (Honours) (Faculty of Human Sciences - Department of Psychology)
Has the new personnel received a copy of the approved application?	Yes
Describe the role of the new personnel in this study	Preparing and conducting research sessions, analysing and summarising data.
Does the new personnel require any training or supervision. If so please describe.	Training and supervision will be conducted by Nicholas Badcock
E-mail address: (Students: Please use your MQ student email address)	penny.kirk@students.mq.edu.au
Tel No. (W):	N/A
Tel No: (H):	02 9528 2995
Mobile No:	0448 377 923
Fax number:	N/A
Does the PICF/Study documents require updating	☐ No ← OR → ☒ Yes (if yes please attach tracked and clean copies of the amended documents)
Working with children and young people (please mark one with an X)	N/A ☒ Working with children check – details attached ☐ Prohibited Employment Declaration Form attached ☐ Currently employed as a teacher in Australia ☐ Other evidence attached ☐

Name:	Peta Larkin
Title:	Miss
Personnel type:	☐Staff ← OR → ☒ Student
Staff / Student no.:	43279317

Qualifications:	N/A
Positions held: (if student, specify Faculty, Department, degree and course in which enrolled)	Faculty of Human Sciences Bachelor of Psychology(Honours)
Has the new personnel received a copy of the approved application?	Yes
Describe the role of the new personnel in this study	Researcher
Does the new personnel require any training or supervision. If so please describe.	
E-mail address: (Students: Please use your MQ student email address)	peta.larkin@mq.students.edu.au
Tel No. (W):	0402673004
Tel No: (H):	
Mobile No:	0402673004
Fax number:	
Does the PICF/Study documents require updating	☐ No ← OR → ☒ Yes (if yes please attach tracked and clean copies of the amended documents)
Working with children and young people (please mark one with an X)	N/A ☒ Working with children check – details attached ☐ Prohibited Employment Declaration Form attached ☐ Currently employed as a teacher in Australia ☐ Other evidence attached ☐

11. <u>Removing research personnel:</u>

Include the below details for new research personnel being removed from the study.

Name:	
Title:	
Personnel type:	☐ Staff ← OR → ☐ Student
Does the PICF/Study documents require updating	☐ No ← OR → ☐ Yes (if yes please attach tracked and clean copies of the amended documents)

Please copy and paste this section for more than one personnel change.

12. <u>Documents:</u>

List all amended documents to be reviewed. These must match the documents submitted as part of this amendment.

Document Title	*Version Number (if applicable)*	*Date (if applicable)*
All attached in single document	5-1, 5-2, 5-3, 5-4	10-March-2017

IMPORTANT NOTICE: ELECTRONIC SUBMISSION OF THIS FORM IS EQUIVALENT TO THE SIGNATURE OF THE CHIEF INVESTIGATOR.

Project 5-1: The lateralisation of spatial ability (Honours 1)

Study Name: 'The Lateralisation of Spatial Ability'

Abstract: The aim of this study is to investigate the relationship between the cerebral lateralization of spatial ability and performance on behavioural measures of visuospatial ability.

Description:
This experiment uses functional Transcranial Ultrasound (fTCD) to measure blood flow velocity in the cerebral arteries of the brain during a spatial task. By comparing the velocity difference between the two hemispheres, we can estimate which hemisphere is dominant for visuospatial ability. In this experiment you will see a series of horizontal lines bisected either to the right or left of the mid-point by a vertical line. The task is to determine whether the vertical line is located to the right or left of the exact middle point. This may take up to 1 hour.

You will also be asked to complete three perceptual reasoning tasks from the Wecshler Adult Intelligence scale; results from these tests will be used to estimate general level of spatial ability. This part of the session will last approximately 1 hour.

Testing is done in the Hearing Hub (south of campus, past the library). Participants should use the main entrance and wait in the reception area on level 1.

Eligibility Requirements: N/A

Duration: 2 hours

Pay: Course credit

Project 5-2: Cognitive Flexibility and Laterality (Honours 2)
Title: Cognitive Flexibility and Laterality

Abstract: We are running an experiment to investigate the relationship between cognitive flexibility and laterality.

Experiment Description: This experiment uses functional Transcranial Ultrasound (fTCD) to measure blood flow velocity in the cerebral arteries of the brain during cognitive activity. By comparing the velocity difference between the two hemispheres, we can estimate laterality or which hemisphere is dominant for a particular cognitive function. Participants will also be required to complete a demographic questionnaire, and undertake a series of short drives on a driving simulator on the right-hand side of the road.

Testing is done in the hearing hub (south of campus, past the library). Participants should use the main entry and wait in the reception area on level 3. After completion participants will be directed to the simulation hub.

Eligibility requirements: Aged 18+ years holding a current Australian provisional 1, provisional 2 or full drivers license

Students who suffer from either migraines or epilepsy, or feel uncomfortable when playing video games or watching 3D movies, are advised that they do not participate in this study.

Duration/pay: The experiment will last for approximately 2 hours and students will be awarded course credit (4 credits) for their time.

The research is being conducted by Ms Peta Larkin as part of her honours project supervised by Dr Nicholas Badcock in the Department of Cognitive Science, Australian Hearing Hub at Macquarie University and Dr Eugene Chekaluk in the Department of Psychology at Macquarie University.

Investigator's name: Peta Larkin
Email: peta.larkin@students.mq.edu.au
Phone: 0431 485 790

Project 5-3: Lab environment and language lateralisation (Masters of Research)

Study Name:

'Does the lab environment influence the measurement of language?'

Abstract:

The purpose of the study is to investigate whether various neuroimaging lab environments influence the measurement of hemispheric language dominance.

Description:

In this study, we are interested in whether various neuroimaging lab environments influence the measurement of which brain hemisphere is dominant for language. To investigate, you will be asked to perform a language task under different conditions. During the language task, a letter will appear on a computer screen and you will be asked to think of words starting with that letter. In one condition, you will be asked to perform this task whilst sitting upright in a quiet room (i.e., the functional Transcranial Doppler Ultrasound neuroimaging environment). In the other condition, you will be asked to perform the same task whilst lying down inside a noisy tunnel (i.e., simulating the functional Magnetic Resonance Imaging environment).

We will measure hemispheric language dominance using functional Transcranial Doppler Ultrasound in both conditions. This technique records blood flow velocity in the left and right cerebral arteries of the brain during cognitive processing. By comparing the velocity difference between the left and right brain hemispheres, we can estimate which hemisphere is dominant for a particular cognitive function (in this case, language). This technique is safe and commonly used. It involves wearing a headset with fixed ultrasound probes and applying some gel to the temples to help measure the signal. This may take up to 1 hour. You will also be asked to complete a handedness test. This part of the session will last approximately 10 minutes. Testing is done in the Hearing Hub (south of campus, past the library). Participants should use the main entrance and wait in the reception area on level 1.

Eligibility Requirements: Fluent in English; normal or corrected-to-normal vision and hearing; does not suffer from severe claustrophobia

Duration: 1.5 hours

Pay: $15 per hour or course credit

Project 5-4: The Lateralisation of Cognitive Functions - Crowding (Other)

Study name: Crowding – Lateralisation in Cognitive Functions

Brief Abstract: The purpose of this study is to test whether the causal hypothesis or the statistical hypothesis best explains lateralisation when considering a broad range of handedness

Detailed Description:
Your brain has two hemispheres, a left and a right. There is debate about which hemisphere is taking control of processing language, and which hemisphere is taking control of your spatial awareness.

Surely one hemisphere cannot be processing *both* language and spatial awareness… or can it? Take part in our study to help us find out more.

Take a seat and let us record the velocity of your blood flow from your middle cerebral artery to each hemisphere of your brain while you complete a word generation task.

We record the blood flow using fTCD – it sounds fancy, but it's a non-invasive ultrasound method which requires a headset to be worn, with a little bit of gel put on each of your temples, or just in front of your ears. This can be removed after the session with tissues or water and a hand towel that is provided.

Testing is completed in the Australian Hearing Hub (south of campus, past the library). Use the lifts in front of Piccolo Me café to gain access to Level 3. Please wait in the reception area.

Eligibility Requirements: None

Duration: 90minutes

Credits: 3

Project 5-4: email text

Have you ever wondered what is going on in your brain when you are doing two completely different tasks at once? Like driving and talking on the phone? – on Bluetooth of course!

What's this all about?

Your brain has two hemispheres, a left and a right. There is debate about which hemisphere is taking control of processing language, and which hemisphere is taking control of your spatial awareness.

Surely one hemisphere cannot be processing *both* language and spatial awareness… or can it?

Take part in our study to help us find out more – is it possible that one of your cerebral hemispheres is an over-achiever and the other one has taken a chill pill? Or does each of your hemispheres like to share the load? Sharing is caring after all!

What do you have to do?

Take a seat for 1.5-2 hours and let us record the velocity of your blood flow from your middle cerebral artery to each hemisphere of your brain while you complete a word generation task.

We record the blood flow using fTCD – it sounds fancy, but it's a non-invasive ultrasound method which requires a headset to be worn with a little bit of gel put on each of your temples, or just in front of your ears. This can be removed after the session with tissues or water and a hand towel that is provided.

Some more advantages include getting most of your course credit in just one sitting and the provision of a free bottle of water and sweet treats is promised.

Any questions?

Feel free to contact Nicola Filardi at nicola.filardi@mq.edu.au with any questions you may have about the study or about timeslot availability.

We look forward to hearing from you!

Dr Nicholas Badcock and Nicola Filardi

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MACQUARIE University

Participant Information Sheet

Name of Project: The Lateralisation of Spatial Ability

Dear Participant,

We would like to invite you to participate in a study of the lateralisation of spatial ability. The testing for this study is being conducted on behalf of the below named researchers, and is supported by Macquarie University and The Australia Research Council Centre of Excellence in Cognition and its Disorders.

What is the study about?

The study aims to better understand the relationship between where brain activity occurs during spatial tasks and an individual's performance on these tasks. We are interested in whether a person's spatial ability is related to which part of the brain is most active during these tasks, for example in the left or right hemisphere.

Who can participate in the study?

We are looking for people aged between 17 and 100 years to participate.

What is involved?

There are two parts to the study.
The **first part** involves completing a spatial task while we record the speed of blood flow in the brain using ultrasound. This technique is safe and very commonly used. It involves wearing a headset and some gel on the temples or scalp to help measure the signal. In addition, the spatial task involves making judgements about the location of a bisecting line along a horizontal plane.
The **second part** involves completing a series of perceptual reasoning tests from the fourth edition of the Wechsler Adult Intelligence Scale (WAIS-IV). The purpose of these tests is to obtain a behavioural measure of spatial ability as it relates to brain activity.

How long will it take?

Each part of the study may take up to 1 hour, with total session time being no more than 2 hours.

Are there any risks or side-effects associated with the study?

There are no known risks or side-effects of the tasks used in this study.

Participants may be left with a small amount of gel on the head or in their hair, which is best removed by washing.

Are there any benefits for participating in the study?

There are no direct benefits for participation in the study. Participants will be rewarded with course credit for assisting with the study.

Other information

All of the data collected as part of the study will be recorded for later analysis and publication in scientific journals.

All other information and personal details will be confidential (*except as required by law*). Only the research team will have access to the data, which will be kept on secure electronic storage devices and locked cabinets, and will be identified by code numbers and not names. No individual participant will be identified in any publication.

The research is being conducted by Miss Penny Kirk (penny.kirk@students.mq.edu.au) to meet the requirements for the degree of Bachelor of Psychology under the supervision of Dr Nicholas Badcock (9850 4067 or nicholas.badcock@mq.edu.au).

Participation in this project is voluntary, and participants are free to withdraw from the study at any time.

Thank you for taking time to consider being involved in this research. It is only through the support of people like yourself that we can make discoveries about the lateralisation of spatial abilities. If you are happy to help us with our research, please complete both copies of the consent form attached, keeping one for yourself and returning the other to the researcher. If you have any questions, please contact Nicholas Badcock on 9850 4067 or nicholas.badcock@mq.edu.au.

Yours sincerely,

Nicholas Badcock and the Research Team

Miss Penny Kirk	Miss Hannah Rappaport	Professor Greg Savage
Miss Peta Larkin	Miss Nicola Filardi	

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Consent Form

Name of Project: The Lateralisation of Spatial Ability

I, (participant's name):

have read *(or, where appropriate, have had read to me)* and understand the information about this study and any questions I have asked have been answered to my satisfaction. **I agree to my participation in this research, knowing that I am is free to withdraw from the study at any time without consequence.** I have been given a copy of this form to keep.

Name of participant: _____

Signature of participant: _____ Date: _____

Investigator's Name: _____

Investigator's Signature: _____ Date: _____

I am happy for **audio recordings** to be used for training and presentation purposes:	Yes ☐	No ☐
I am happy for **video recordings** to be used for training and presentation purposes:	Yes ☐	No ☐
I am happy for **photographs** of to be used for training and presentation purposes:	Yes ☐	No ☐
I am happy to be contacted about new research projects in the future:	Yes ☐	No ☐

The ethical aspects of this study have been approved by the Macquarie University Human Research Ethics Committee. If you have any complaints or reservations about any ethical aspect of your participation in this research, you may contact the Committee through the Director, Research Ethics and Integrity (telephone (02) 9850 7854; email ethics@mq.edu.au). Any complaint you make will be treated in confidence and investigated, and you will be informed of the outcome.

In the unlikely event of experiencing distress through involvement in this research, you will have the opportunity to discuss any such issues further with the research of your session or you can contact Dr Nicholas Badcock. Alternatively, there is free counselling available 24 hours a day by phone through Lifeline (phone 13 11 14) and a comprehensive list of clinical psychologists is available through the Australian Psychological Society (phone 1800 333 497, or website **http://www.psychology.org.au**). The experimenter can give you further information about these services or assist you in contacting them if you wish.

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MACQUARIE University

Participant and Parent Information Sheet

Name of Project: Cognitive Flexibility and Laterality

Dear Participant,

We would like to invite you to participate in a study of the lateralisation of cognitive functions. The testing for this study is being conducted on behalf of the below named researchers, and is supported by Macquarie University and The Australia Research Council Centre of Excellence in Cognition and its Disorders.

What is the study about?

The study aims to understand the relationship between cognitive flexibility (CF) and laterality. CF is expected to be important in our ability to perform novel tasks. In this experiment it will be assessed by participants' performance on a driving simulation on the opposite side of the road to usual. Additionally, laterality will be assessed using Functional Transcranial Ultrasound (fTCD). The relationship between performance on the novel driving task and fTCD will be examined.

Who can participate in the study?

Participants will be first, or second year (PSY246), psychology students aged over 18. Participants will be required to hold a current Australian drivers licence, of at least provisional level. Participants holding an international drivers licence will not be admitted. If you experience epilepsy or migraines, or experience physical uneasiness during 3D movies or video games, it is advised that you do not participate in this study as you might find the simulator experience makes you feel unwell

What is involved?

There are two parts to the study. The **first part** involves completing a verbal and/or spatial task while we record the speed of blood flow in the brain. This involves wearing a headset and some gel on the temples or scalp to help measure the signal. To measure blood flow, we use ultrasound. This is a safe and common procedure.
The **second part** requires participants to complete a short series of drives on the simulator. The initial drive will be a practice drive, to allow you to become familiar with the vehicle and the controls. The subsequent drive will take approximately ten minutes.

How long will it take?

In total the study may take up to 2 hours to complete. Typically sessions will be shorter than this. The researcher will confirm the time frame of the sessions.

Are there any risks or side-effects associated with the study?

Participants may be left with a small amount of gel on the head or in their hair, which is best removed by washing. The driving simulator can involve possible risk of physical discomfort in the form of motion sickness.

Are there any benefits for participating in the study?

You will be compensated with 2-hour (4 points) course credit for your participation in this study.

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MACQUARIE University

Participant Information Sheet

Name of Project: Language Measurement in Various Brain Imaging Lab Environments

Dear Participant,

We would like to invite you to participate in a study exploring the measurement of language processing in various brain imaging lab environments. The testing for this study is being conducted on behalf of the below named researchers, and is supported by Macquarie University and The Australia Research Council Centre of Excellence in Cognition and its Disorders.

What is the study about?

The study aims to better understand how various brain imaging lab environments might influence the measurement of hemispheric language dominance. This could have implications for the brain imaging tools that researchers choose to measure cognitive processes, such as language.

Who can participate in the study?

We are looking for people aged 17 years and over to participate.

What is involved?

In this study, we are interested in whether various neuroimaging lab environments influence the measurement of which brain hemisphere is dominant for language. To investigate, you will be asked to perform a language task under different conditions. During the language task, a letter will appear on a computer screen and you will be asked to think of words starting with that letter. In one condition, you will be asked to perform this task whilst sitting upright in a quiet room (i.e., the functional Transcranial Doppler Ultrasound neuroimaging environment). In the other condition, you will be asked to perform the same task whilst lying down inside a noisy tunnel (i.e., simulating the functional Magnetic Resonance Imaging environment).

We will measure hemispheric language dominance using functional Transcranial Doppler Ultrasound in both conditions. This technique records blood flow velocity in the left and right cerebral arteries of the brain during cognitive processing. By comparing the velocity difference between the left and right brain hemispheres, we can estimate which hemisphere is dominant for a particular cognitive function (in this case, language). This technique is safe and commonly used. It involves wearing a headset with fixed ultrasound probes and applying some gel to the temples to help measure the signal. This may take up to 1 hour. You will also be asked to complete a handedness test. This part of the session will last approximately 10 minutes. Testing is done in the Hearing Hub (south of campus, past the library). Participants should use the main entrance and wait in the reception area on level 1.

How long will it take?

The study may take up to 1.5 hours. The researcher will confirm the time frame of the sessions.

Are there any risks or side-effects associated with the study?

There are no known risks or side-effects of the tasks used in this study.

Participants may be left with a small amount of gel on the head or in their hair, which is best removed with a tissue or by washing.

Are there any benefits for participating in the study?

There are no direct benefits for participation in the study. Participants will be rewarded with course credit or $15 per hour (or pro rata) for assisting with the study.

Audio and video recordings and photographs may be made

Audio and video recording of the responses *may be made* for later scoring, training, and presentation purposes. Photographs of our testing session may be also taken for training and presentation purposes. These recordings and photographs will allow us to provide a clear picture of the testing situation when training researchers to assist with the project and when describing the testing situation in research presentations. If you are happy for these recordings and photographs to be used for training and presentation purposes, please check the boxes after the signature on the next page.

Other information

All of the data collected as part of the study will be recorded for later analysis and publication in scientific journals.

All other information and personal details will be confidential (*except as required by law*). Only the research team will have access to the data, which will be kept on secure electronic storage devices and locked cabinets, and will be identified by code numbers and not names.

The research is being conducted to meet the requirements for the degree of Bachelor of Psychology under the supervision of Dr Nicholas Badcock (9850 4067 or nicholas.badcock@mq.edu.au).

Participation in this project is voluntary, and participants are free to withdraw from the study at any time.

Thank you for taking time to consider being involved in this research. It is only through the support of people like yourself that we can make discoveries about cognitive functions and the tools we use to measure them. If you are happy to help us with our research, please complete both copies of the consent form attached, keeping one for yourself and returning the other to the researcher. If you have any questions, please contact Nicholas Badcock on 9850 4067 or nicholas.badcock@mq.edu.au.

Yours sincerely,

Nicholas Badcock and the Research Team

Dr Ivan Yuen	Ms Nicola Filardi	Ms Vanessa Dennis	Mrs Trudy Green
Prof Katherine Demuth	Mrs Julianne Pascoe	Ms Hannah Rapaport	Dr Margriet Groen
Prof Dorothy Bishop	Mrs Ann Carrigan	Dr Isabelle Boisvert	Mr Nathan Caruana
Ms Leidy Castro-Meneses	Ms Trudy Krajenbrink	A/Prof Gen McArthur	A/Prof Cath McMahon
Mr Andrew Roberts	Mr Giles King	Ms Maia Zucco	Mr Jordan Wehrman

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Consent Form

Name of Project: The Lateralisation of Cognitive Functions

I, (participant or parents/guardian's name):

have read *(or, where appropriate, have had read to me)* and understand the information about this study and any questions I have asked have been answered to my satisfaction. **I agree to my participation in this research, knowing that I am free to withdraw from the study at any time without consequence.** I have been given a copy of this form to keep.

Name of participant: _____

Signature of participant: _____ Date: _____

Investigator's Name: _____

Investigator's Signature: _____ Date: _____

I am happy for **audio recordings** to be used for training and presentation purposes:	Yes ☐	No ☐
I am happy for **video recordings** to be used for training and presentation purposes:	Yes ☐	No ☐
I am happy for **photographs** of to be used for training and presentation purposes:	Yes ☐	No ☐
I am happy to be contacted about new research projects in the future:	Yes ☐	No ☐

The ethical aspects of this study have been approved by the Macquarie University Human Research Ethics Committee. If you have any complaints or reservations about any ethical aspect of your participation in this research, you may contact the Committee through the Director, Research Ethics and Integrity (telephone (02) 9850 7854; email ethics@mq.edu.au). Any complaint you make will be treated in confidence and investigated, and you will be informed of the outcome.

In the unlikely event of experiencing distress through involvement in this research, you will have the opportunity to discuss any such issues further with the research of your session or you can contact Dr Nicholas Badcock. Alternatively, there is free counselling available 24 hours a day by phone through Lifeline (phone 13 11 14) and a comprehensive list of clinical psychologists is available through the Australian Psychological Society (phone 1800 333 497, or website **http://www.psychology.org.au**). The experimenter can give you further information about these services or assist you in contacting them if you wish.

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Participant and Parent Information Sheet

Name of Project: The Lateralisation of Cognitive Functions - Crowding

Dear Participant or Parent/guardian,

We would like to invite you to participate in a study of the lateralisation of cognitive functions. The testing for this study is being conducted on behalf of the below named researchers, and is supported by Macquarie University and The Australia Research Council Centre of Excellence in Cognition and its Disorders.

What is the study about?

The study aims to better understand the relationship between where brain activity occurs during language and spatial tasks and how this changes with experience. This brain activity has been related to language and literacy skills and general cognitive abilities. We are interested in how the relationship between these skills and brain activity changes with experience, for example, as people learn how to read.

Who can participate in the study?

We are looking for people aged between 17 and 100 years to participate.

What is involved?

There are two parts to the study. The researcher will confirm whether you will be involved in one or both parts.

The **first part** involves a screen for the lateralization of language production and spatial processing. The screen will utilise Functional Transcranial Doppler (fTCD) to measure blood flow velocity through your middle cerebral artery. This method is non-evasive. It will require you to wear a headset and have a little gel on either side of your temples. This ultrasound method is safe and commonly used. The tasks will involve generating words to a presented letter and making spatial judgments about the position of lines presented on a computer screen.

The **second part** involves the set up of fTCD once more. You will complete a word-generation task to measure your lateralisation of language production, and another task to measure your brain's lateralisation of spatial attention.

How long will it take?

Each part of the study may take up to 2 hours (4 hours in total) and may be completed in multiple separate sessions. Typically sessions will be shorter than this. The researcher will confirm the time frame of the sessions.

Are there any risks or side-effects associated with the study?

There are no known risks or side-effects of the tasks used in this study.

Participants may be left with a small amount of gel on the head or in their hair, which is best removed by washing.

Are there any benefits for participating in the study?

There are no direct benefits for participation in the study. Participants will be rewarded with course credit or $15 per hour (or pro rata) for assisting with the study.

Audio and video recordings and photographs may be made

Audio and video recording of the responses *may be made* for later scoring, training, and presentation purposes. Photographs of our testing session may be also taken for training and presentation purposes. These recordings and photographs will allow us to provide a clear picture of the testing situation when training researchers to assist with the project and when describing the testing situation in research presentations. If you are happy for these recordings and photographs to be used for training and presentation purposes, please check the boxes after the signature on the next page.

Other information

All of the data collected as part of the study will be recorded for later analysis and publication in scientific journals.

All other information and personal details will be confidential (*except as required by law*). Only the research team will have access to the data, which will be kept on secure electronic storage devices and locked cabinets, and will be identified by code numbers and not names. No individual child will be identified in any publication.

The research is being conducted to meet the requirements for the degree of Bachelor of Psychology under the supervision of Dr Nicholas Badcock (9850 4067 or nicholas.badcock@mq.edu.au).

Participation in this project is voluntary, and participants or their guardians are free to withdraw from the study at any time. If your child is participating in the study, it is important to us that they are happy to be involved in the study. It would be very helpful if you could explain to your child (in simple words) what they would have to do in the study (and that they agree to do it) before they attend a testing session. We will do the same when they come in for a testing session so that we can get their informed consent to be involved in the study.

Thank you for taking time to consider being involved in this research. It is only through the support of people like yourself and your child that we can make discoveries about the lateralisation of cognitive functions. If you, or you and your child, are happy to help us with our research, please complete both copies of the consent form attached, keeping one for yourself and returning the other to the researcher. If you have any questions, please contact Nicholas Badcock on 9850 4067 or nicholas.badcock@mq.edu.au.

Yours sincerely,

Nicholas Badcock and the Research Team

Ms Nicola Filardi Ms Hannah Rapaport Ms Peta Larkin Ms Penny Kirk

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Consent Form

Name of Project: The Lateralisation of Cognitive Functions

I, (participant name):

have read *(or, where appropriate, have had read to me)* and understand the information about this study and any questions I have asked have been answered to my satisfaction. **I agree to my/my child's participation in this research, knowing that I am/my child is free to withdraw from the study at any time without consequence.** I have been given a copy of this form to keep.

Name of participant: _____

Signature of participant: _____ Date: _____

Investigator's Name: _____

Investigator's Signature: _____ Date: _____

I am happy for **audio recordings** to be used for training and presentation purposes:	Yes ☐	No ☐
I am happy for **video recordings** to be used for training and presentation purposes:	Yes ☐	No ☐
I am happy for **photographs** of to be used for training and presentation purposes:	Yes ☐	No ☐
I am happy to be contacted about new research projects in the future:	Yes ☐	No ☐

The ethical aspects of this study have been approved by the Macquarie University Human Research Ethics Committee. If you have any complaints or reservations about any ethical aspect of your participation in this research, you may contact the Committee through the Director, Research Ethics and Integrity (telephone (02) 9850 7854; email ethics@mq.edu.au). Any complaint you make will be treated in confidence and investigated, and you will be informed of the outcome.

In the unlikely event of experiencing distress through involvement in this research, you will have the opportunity to discuss any such issues further with the research of your session or you can contact Dr Nicholas Badcock. Alternatively, there is free counselling available 24 hours a day by phone through Lifeline (phone 13 11 14) and a comprehensive list of clinical psychologists is available through the Australian Psychological Society (phone 1800 333 497, or website **http://www.psychology.org.au**). The experimenter can give you further information about these services or assist you in contacting them if you wish.

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nicholas.badcock@mq.edu.au

ABN 90 952 801 237
CRICOS Provider No 00002J

MACQUARIE University

Participant Information Sheet

Name of Project: The Lateralisation of Spatial Ability

Dear Participant,

We would like to invite you to participate in a study of the lateralisation of spatial ability. The testing for this study is being conducted on behalf of the below named researchers, and is supported by Macquarie University and The Australia Research Council Centre of Excellence in Cognition and its Disorders.

What is the study about?

The study aims to better understand the relationship between where brain activity occurs during spatial tasks and an individual's performance on these tasks. We are interested in whether a person's spatial ability is related to which part of the brain is most active during these tasks, for example in the left or right hemisphere.

Who can participate in the study?

We are looking for people aged between 17 and 100 years to participate.

What is involved?

There are two parts to the study.
The **first part** involves completing a spatial task while we record the speed of blood flow in the brain using ultrasound. This technique is safe and very commonly used. It involves wearing a headset and some gel on the temples or scalp to help measure the signal. In addition, the spatial task involves making judgements about the location of a bisecting line along a horizontal plane.
The **second part** involves completing a series of perceptual reasoning tests from the fourth edition of the Wechsler Adult Intelligence Scale (WAIS-IV). The purpose of these tests is to obtain a behavioural measure of spatial ability as it relates to brain activity.

How long will it take?

Each part of the study may take up to 1 hour, with total session time being no more than 2 hours.

Are there any risks or side-effects associated with the study?

There are no known risks or side-effects of the tasks used in this study.

Participants may be left with a small amount of gel on the head or in their hair, which is best removed by washing.

Are there any benefits for participating in the study?

There are no direct benefits for participation in the study. Participants will be rewarded with course credit for assisting with the study.

Other information

All of the data collected as part of the study will be recorded for later analysis and publication in scientific journals.

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All other information and personal details will be confidential (*except as required by law*). Only the research team will have access to the data, which will be kept on secure electronic storage devices and locked cabinets, and will be identified by code numbers and not names. No individual participant will be identified in any publication.

The research is being conducted by Miss Penny Kirk (penny.kirk@students.mq.edu.au) to meet the requirements for the degree of Bachelor of Psychology under the supervision of Dr Nicholas Badcock (9850 4067 or nicholas.badcock@mq.edu.au).

Participation in this project is voluntary, and participants are free to withdraw from the study at any time.

Thank you for taking time to consider being involved in this research. It is only through the support of people like yourself that we can make discoveries about the lateralisation of spatial abilities. If you are happy to help us with our research, please complete both copies of the consent form attached, keeping one for yourself and returning the other to the researcher. If you have any questions, please contact Nicholas Badcock on 9850 4067 or nicholas.badcock@mq.edu.au.

Yours sincerely,

Nicholas Badcock and the Research Team

Miss Penny Kirk
Miss Hannah Rappaport
Professor Greg Savage
Miss Peta Larkin
Miss Nicola Filardi

Version 5-1: 2017-March-10

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MACQUARIE University

Consent Form

Name of Project: The Lateralisation of Spatial Ability

I, (participant's name):

have read *(or, where appropriate, have had read to me)* and understand the information about this study and any questions I have asked have been answered to my satisfaction. **I agree to my participation in this research, knowing that I am is free to withdraw from the study at any time without consequence.** I have been given a copy of this form to keep.

Name of participant: _____

Signature of participant: _____ Date: _____

Investigator's Name: _____

Investigator's Signature: _____ Date: _____

I am happy for **audio recordings** to be used for training and presentation purposes:	Yes ☐	No ☐
I am happy for **video recordings** to be used for training and presentation purposes:	Yes ☐	No ☐
I am happy for **photographs** of to be used for training and presentation purposes:	Yes ☐	No ☐
I am happy to be contacted about new research projects in the future:	Yes ☐	No ☐

The ethical aspects of this study have been approved by the Macquarie University Human Research Ethics Committee. If you have any complaints or reservations about any ethical aspect of your participation in this research, you may contact the Committee through the Director, Research Ethics and Integrity (telephone (02) 9850 7854; email ethics@mq.edu.au). Any complaint you make will be treated in confidence and investigated, and you will be informed of the outcome.

In the unlikely event of experiencing distress through involvement in this research, you will have the opportunity to discuss any such issues further with the research of your session or you can contact Dr Nicholas Badcock. Alternatively, there is free counselling available 24 hours a day by phone through Lifeline (phone 13 11 14) and a comprehensive list of clinical psychologists is available through the Australian Psychological Society (phone 1800 333 497, or website http://www.psychology.org.au). The experimenter can give you further information about these services or assist you in contacting them if you wish.

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MACQUARIE University

Participant and Parent Information Sheet

Name of Project: Cognitive Flexibility and Laterality

Dear Participant,

We would like to invite you to participate in a study of the lateralisation of cognitive functions. The testing for this study is being conducted on behalf of the below named researchers, and is supported by Macquarie University and The Australia Research Council Centre of Excellence in Cognition and its Disorders.

What is the study about?

The study aims to understand the relationship between cognitive flexibility (CF) and laterality. CF is expected to be important in our ability to perform novel tasks. In this experiment it will be assessed by participants' performance on a driving simulation on the opposite side of the road to usual. Additionally, laterality will be assessed using Functional Transcranial Ultrasound (fTCD). The relationship between performance on the novel driving task and fTCD will be examined.

Who can participate in the study?

Participants will be first, or second year (PSY246), psychology students aged over 18. Participants will be required to hold a current Australian drivers licence, of at least provisional level. Participants holding an international drivers licence will not be admitted. If you experience epilepsy or migraines, or experience physical uneasiness during 3D movies or video games, it is advised that you do not participate in this study as you might find the simulator experience makes you feel unwell.

What is involved?

There are two parts to the study. The **first part** involves completing a verbal and/or spatial task while we record the speed of blood flow in the brain. This involves wearing a headset and some gel on the temples or scalp to help measure the signal. To measure blood flow, we use ultrasound. This is a safe and common procedure.

The **second part** requires participants to complete a short series of drives on the simulator. The initial drive will be a practice drive, to allow you to become familiar with the vehicle and the controls. The subsequent drive will take approximately ten minutes.

How long will it take?

In total the study may take up to 2 hours to complete. Typically sessions will be shorter than this. The researcher will confirm the time frame of the sessions.

Are there any risks or side-effects associated with the study?

Participants may be left with a small amount of gel on the head or in their hair, which is best removed by washing. The driving simulator can involve possible risk of physical discomfort in the form of motion sickness.

Are there any benefits for participating in the study?

You will be compensated with 2-hour (4 points) course credit for your participation in this study.

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Audio and video recordings and photographs may be made

Audio and video recording of the responses *may be made* for later scoring, training, and presentation purposes. Photographs of our testing session may be also taken for training and presentation purposes. These recordings and photographs will allow us to provide a clear picture of the testing situation when training researchers to assist with the project and when describing the testing situation in research presentations. If you are happy for these recordings and photographs to be used for training and presentation purposes, please check the boxes after the signature on the next page.

Other information

All of the data collected as part of the study will be recorded for later analysis and publication in scientific journals.

All other information and personal details will be confidential (*except as required by law*). Only the research team will have access to the data, which will be kept on secure electronic storage devices and locked cabinets, and will be identified by code numbers and not names. No individual will be identified in any publication.

Participation in this project is voluntary, and participants are free to withdraw from the study at any time.

Thank you for taking time to consider being involved in this research. It is only through the support of people like yourself that we can make discoveries about the lateralisation of cognitive functions. If you are happy to help us with our research, please complete both copies of the consent form attached, keeping one for yourself and returning the other to the researcher.

This study is being conducted by Peta Larkin (ph: 0402673004, peta.larkin@students.mq.edu.au) to meet the requirements of Bachelor of Psychology (Honours) under the supervision of Dr Nicholas Badcock (ph: 9850 4067, nicholas.badcock@mq.edu.au) and Dr Eugene Chekaluk of the Department of Psychology (ph.: 9850 8009, eugene.chekaluk@mq.edu.au). If you have any questions, please use contact information provided above.

Yours sincerely,

Peta Larkin and the Research Team

Dr Nicholas Badcock	Ms Nicola Filardi
Dr Eugene Chekaluk	Ms Claris Teng
Ms Penny Kirk	Ms Hannah Rapaport

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MACQUARIE University

Consent Form

Name of Project: The Lateralisation of Cognitive Functions

I, (participant's name): _____

have read *(or, where appropriate, have had read to me)* and understand the information about this study and any questions I have asked have been answered to my satisfaction. **I agree to my participation in this research, knowing that I am free to withdraw from the study at any time without consequence.** I have been given a copy of this form to keep.

Name of participant: _____

Signature of participant: _____ Date: _____

Investigator's Name: _____

Investigator's Signature: _____ Date: _____

I am happy for **audio recordings** to be used for training and presentation purposes:	Yes ☐	No ☐
I am happy for **video recordings** to be used for training and presentation purposes:	Yes ☐	No ☐
I am happy for **photographs** of to be used for training and presentation purposes:	Yes ☐	No ☐
I am happy to be contacted about new research projects in the future:	Yes ☐	No ☐

The ethical aspects of this study have been approved by the Macquarie University Human Research Ethics Committee. If you have any complaints or reservations about any ethical aspect of your participation in this research, you may contact the Committee through the Director, Research Ethics and Integrity (telephone (02) 9850 7854; email ethics@mq.edu.au). Any complaint you make will be treated in confidence and investigated, and you will be informed of the outcome.

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involves completing a series ability tests (eg language and literacy, mathematics, handedness, and general ability questionnaire). These tasks are of interest as they may be related to the brain activity.

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Each part of the study may take up to 2 hours (4 hours in total) and may be completed in multiple separate sessions. Typically sessions will be shorter than this especially for research involving infants and children. The researcher will confirm the time frame of the sessions.

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If your child is participating in the study, it is important to us that they are happy to be involved in the study. It would be very helpful if you could explain to your child (in simple words) what they would have to do in the study (and that they agree to do it) before they attend a testing session. We will do the same when they come in for a testing session so that we can get their informed consent to be involved in the study.

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If you have any questions, please contact Nicholas Badcock on 9850 4067 or nicholas.badcock@mq.edu.au.

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Ms Leidy Castro-Meneses
Mr Andrew Roberts
Ms Trudy Krajenbrink
Mr Giles King

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If signing as a parent/guardian, I have explained the study to my child who has agreed to take part in the research. They understand that they can withdraw from the study at any time.
Children may sign the 'participant' section (above) of the form if the parent/guardian wishes.

Name of parent/guardian: _____

Signature of parent/guardian: _____ Date: _____

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nicholas.badcock@mq.edu.au

ABN 90 952 801 237
CRICOS Provider No 00002J

MACQUARIE University

Participant Information Sheet

Name of Project: Language Measurement in Various Brain Imaging Lab Environments

Dear Participant,

We would like to invite you to participate in a study exploring the measurement of language processing in various brain imaging lab environments. The testing for this study is being conducted on behalf of the below named researchers, and is supported by Macquarie University and The Australia Research Council Centre of Excellence in Cognition and its Disorders.

What is the study about?

The study aims to better understand how various brain imaging lab environments might influence the measurement of hemispheric language dominance. This could have implications for the brain imaging tools that researchers choose to measure cognitive processes, such as language.

Who can participate in the study?

We are looking for people aged 17 years and over to participate.

What is involved?

In this study, we are interested in whether various neuroimaging lab environments influence the measurement of which brain hemisphere is dominant for language. To investigate, you will be asked to perform a language task under different conditions. During the language task, a letter will appear on a computer screen and you will be asked to think of words starting with that letter. In one condition, you will be asked to perform this task whilst sitting upright in a quiet room (i.e., the functional Transcranial Doppler Ultrasound neuroimaging environment). In the other condition, you will be asked to perform the same task whilst lying down inside a noisy tunnel (i.e., simulating the functional Magnetic Resonance Imaging environment).

We will measure hemispheric language dominance using functional Transcranial Doppler Ultrasound in both conditions. This technique records blood flow velocity in the left and right cerebral arteries of the brain during cognitive processing. By comparing the velocity difference between the left and right brain hemispheres, we can estimate which hemisphere is dominant for a particular cognitive function (in this case, language). This technique is safe and commonly used. It involves wearing a headset with fixed ultrasound probes and applying some gel to the temples to help measure the signal. This may take up to 1 hour. You will also be asked to complete a handedness test. This part of the session will last approximately 10 minutes. Testing is done in the Hearing Hub (south of campus, past the library). Participants should use the main entrance and wait in the reception area on level 1.

How long will it take?

The study may take up to 1.5 hours. The researcher will confirm the time frame of the sessions.

Are there any risks or side-effects associated with the study?

There are no known risks or side-effects of the tasks used in this study.

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Participants may be left with a small amount of gel on the head or in their hair, which is best removed with a tissue or by washing.

Are there any benefits for participating in the study?

There are no direct benefits for participation in the study. Participants will be rewarded with course credit or $15 per hour (or pro rata) for assisting with the study.

Audio and video recordings and photographs may be made

Audio and video recording of the responses *may be made* for later scoring, training, and presentation purposes. Photographs of our testing session may be also taken for training and presentation purposes. These recordings and photographs will allow us to provide a clear picture of the testing situation when training researchers to assist with the project and when describing the testing situation in research presentations. If you are happy for these recordings and photographs to be used for training and presentation purposes, please check the boxes after the signature on the next page.

Other information

All of the data collected as part of the study will be recorded for later analysis and publication in scientific journals.

All other information and personal details will be confidential (*except as required by law*). Only the research team will have access to the data, which will be kept on secure electronic storage devices and locked cabinets, and will be identified by code numbers and not names.

The research is being conducted to meet the requirements for the degree of Bachelor of Psychology under the supervision of Dr Nicholas Badcock (9850 4067 or nicholas.badcock@mq.edu.au).

Participation in this project is voluntary, and participants are free to withdraw from the study at any time.

Thank you for taking time to consider being involved in this research. It is only through the support of people like yourself that we can make discoveries about cognitive functions and the tools we use to measure them. If you are happy to help us with our research, please complete both copies of the consent form attached, keeping one for yourself and returning the other to the researcher. If you have any questions, please contact Nicholas Badcock on 9850 4067 or nicholas.badcock@mq.edu.au.

Yours sincerely,

Nicholas Badcock and the Research Team

Dr Ivan Yuen	Ms Nicola Filardi	Ms Vanessa Dennis	Mrs Trudy Green
Prof Katherine Demuth	Mrs Julianne Pascoe	Ms Hannah Rapaport	Dr Margriet Groen
Prof Dorothy Bishop	Mrs Ann Carrigan	Dr Isabelle Boisvert	Mr Nathan Caruana
Ms Leidy Castro-Meneses	Ms Trudy Krajenbrink	A/Prof Gen McArthur	A/Prof Cath McMahon
Mr Andrew Roberts	Mr Giles King	Ms Maia Zucco	Mr Jordan Wehrman

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nicholas.badcock@mq.edu.au

ABN 90 952 801 237
CRICOS Provider No 00002J

MACQUARIE University

Consent Form

Name of Project: The Lateralisation of Cognitive Functions

I, (participant or parents/guardian's name):

have read *(or, where appropriate, have had read to me)* and understand the information about this study and any questions I have asked have been answered to my satisfaction. **I agree to my participation in this research, knowing that I am free to withdraw from the study at any time without consequence.** I have been given a copy of this form to keep.

Name of participant: _____

Signature of participant: _____ Date: _____

_____

_____ Date: _____

Investigator's Name: _____

Investigator's Signature: _____ Date: _____

I am happy for **audio recordings** to be used for training and presentation purposes:	Yes ☐	No ☐
I am happy for **video recordings** to be used for training and presentation purposes:	Yes ☐	No ☐
I am happy for **photographs** of to be used for training and presentation purposes:	Yes ☐	No ☐
I am happy to be contacted about new research projects in the future:	Yes ☐	No ☐

The ethical aspects of this study have been approved by the Macquarie University Human Research Ethics Committee. If you have any complaints or reservations about any ethical aspect of your participation in this research, you may contact the Committee through the Director, Research Ethics and Integrity (telephone (02) 9850 7854; email ethics@mq.edu.au). Any complaint you make will be treated in confidence and investigated, and you will be informed of the outcome.

In the unlikely event of experiencing distress through involvement in this research, you will have the opportunity to discuss any such issues further with the research of your session or you can contact Dr Nicholas Badcock. Alternatively, there is free counselling available 24 hours a day by phone through Lifeline (phone 13 11 14) and a comprehensive list of clinical psychologists is available through the Australian Psychological Society (phone 1800 333 497, or website **http://www.psychology.org.au**). The experimenter can give you further information about these services or assist you in contacting them if you wish.

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the relationship between where brain activity occurs during language and spatial tasks and how this changes with experience. This brain activity has been related to language and literacy skills and general cognitive abilities. We are interested in how the relationship between these skills and brain activity changes with experience, for example, as people learn how to read.

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There are two parts to the study. The researcher will confirm whether you will be involved in one or both parts.

The **first part** involves completing a verbal and/or spatial task while we record the speed of blood flow in the brain or the brain's electrical activity. Both of these involve wearing a headset and some gel on the temples or scalp to help measure the signal. To measure blood flow, we use ultrasound. To measure electrical activity, we use electroencephalography or EEG. Both of these are safe and very commonly used. We will measure the brain's response to decisions about words and letters or pictures and symbols.

Ultrasounds recordings of tongue movement may also be made. This involves resting a device under the chin with gel to help measure the signal.

The **second part** involves completing a series ability tests (eg language and literacy, mathematics, handedness, and general ability questionnaire). These tasks are of interest as they may be related to the brain activity.

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If signing as a parent/guardian, I have explained the study to my child who has agreed to take part in the research. They understand that they can withdraw from the study at any time.
Children may sign the 'participant' section (above) of the form if the parent/guardian wishes.

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Signature of parent/guardian: _____ Date: _____

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nicholas.badcock@mq.edu.au

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CRICOS Provider No 00002J

MACQUARIE University

Participant and Parent Information Sheet

Name of Project: The Lateralisation of Cognitive Functions - Crowding

Dear Participant or Parent/guardian,

We would like to invite you to participate in a study of the lateralisation of cognitive functions. The testing for this study is being conducted on behalf of the below named researchers, and is supported by Macquarie University and The Australia Research Council Centre of Excellence in Cognition and its Disorders.

What is the study about?

The study aims to better understand the relationship between where brain activity occurs during language and spatial tasks and how this changes with experience. This brain activity has been related to language and literacy skills and general cognitive abilities. We are interested in how the relationship between these skills and brain activity changes with experience, for example, as people learn how to read.

Who can participate in the study?

We are looking for people aged between 17 and 100 years to participate.

What is involved?

There are two parts to the study. The researcher will confirm whether you will be involved in one or both parts.

The **first part** involves a screen for the lateralization of language production and spatial processing. The screen will utilise Functional Transcranial Doppler (fTCD) to measure blood flow velocity through your middle cerebral artery. This method is non-evasive. It will require you to wear a headset and have a little gel on either side of your temples. This ultrasound method is safe and commonly used. The tasks will involve generating words to a presented letter and making spatial judgments about the position of lines presented on a computer screen.

The **second part** involves the set up of fTCD once more. You will complete a word-generation task to measure your lateralisation of language production, and another task to measure your brain's lateralisation of spatial attention.

How long will it take?

Each part of the study may take up to 2 hours (4 hours in total) and may be completed in multiple separate sessions. Typically sessions will be shorter than this. The researcher will confirm the time frame of the sessions.

Are there any risks or side-effects associated with the study?

There are no known risks or side-effects of the tasks used in this study.

Participants may be left with a small amount of gel on the head or in their hair, which is best removed by washing.

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Are there any benefits for participating in the study?

There are no direct benefits for participation in the study. Participants will be rewarded with course credit or $15 per hour (or pro rata) for assisting with the study.

Audio and video recordings and photographs may be made

Audio and video recording of the responses *may be made* for later scoring, training, and presentation purposes. Photographs of our testing session may be also taken for training and presentation purposes. These recordings and photographs will allow us to provide a clear picture of the testing situation when training researchers to assist with the project and when describing the testing situation in research presentations. If you are happy for these recordings and photographs to be used for training and presentation purposes, please check the boxes after the signature on the next page.

Other information

All of the data collected as part of the study will be recorded for later analysis and publication in scientific journals.

All other information and personal details will be confidential (*except as required by law*). Only the research team will have access to the data, which will be kept on secure electronic storage devices and locked cabinets, and will be identified by code numbers and not names. No individual child will be identified in any publication.

The research is being conducted to meet the requirements for the degree of Bachelor of Psychology under the supervision of Dr Nicholas Badcock (9850 4067 or nicholas.badcock@mq.edu.au).

Participation in this project is voluntary, and participants or their guardians are free to withdraw from the study at any time. If your child is participating in the study, it is important to us that they are happy to be involved in the study. It would be very helpful if you could explain to your child (in simple words) what they would have to do in the study (and that they agree to do it) before they attend a testing session. We will do the same when they come in for a testing session so that we can get their informed consent to be involved in the study.

Thank you for taking time to consider being involved in this research. It is only through the support of people like yourself and your child that we can make discoveries about the lateralisation of cognitive functions. If you, or you and your child, are happy to help us with our research, please complete both copies of the consent form attached, keeping one for yourself and returning the other to the researcher. If you have any questions, please contact Nicholas Badcock on 9850 4067 or nicholas.badcock@mq.edu.au.

Yours sincerely,

Nicholas Badcock and the Research Team

Ms Nicola Filardi	Ms Hannah Rapaport	Ms Peta Larkin	Ms Penny Kirk

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MACQUARIE University

Consent Form

Name of Project: The Lateralisation of Cognitive Functions

I, (participant name):

have read *(or, where appropriate, have had read to me)* and understand the information about this study and any questions I have asked have been answered to my satisfaction. **I agree to my/my child's participation in this research, knowing that I am/my child is free to withdraw from the study at any time without consequence.** I have been given a copy of this form to keep.

Name of participant:

Signature of participant: Date:

Investigator's Name:

Investigator's Signature: Date:

I am happy for **audio recordings** to be used for training and presentation Yes ☐ No ☐ purposes:

I am happy for **video recordings** to be used for training and presentation Yes ☐ No ☐ purposes:

I am happy for **photographs** of to be used for training and presentation Yes ☐ No ☐ purposes:

I am happy to be contacted about new research projects in the future: Yes ☐ No ☐

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verbal and/or spatial task while we record the speed of

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in the brain or the brain's electrical activity. Both of these involve wearing

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or scalp to help measure the signal. To measure blood flow, we use

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. To measure electrical activity, we use electroencephalography or EEG. Both of these are

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We will measure the brain's response to decisions about words and letters or pictures and symbols.

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Ultrasounds recordings of tongue movement may also be made. This involves resting a device under the chin with gel to help measure the signal.

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and literacy, mathematics, handedness, and general ability questionnaire). These tasks are of interest as they may be related

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especially for research involving infants and children.

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Prof Katherine Demuth	Mrs Julianne Pascoe	Ms Hannah Rapaport	Dr Margriet Groen
Prof Dorothy Bishop	Mrs Ann Carrigan	Dr Isabelle Boisvert	Mr Nathan Caruana
Ms Leidy Castro-Meneses	Ms Trudy Krajenbrink	A/Prof Gen McArthur	A/Prof Cath McMahon
Mr Andrew Roberts	Mr Giles King	Ms Maia Zucco	Mr Jordan Wehrman

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If signing as a parent/guardian, I have explained the study to my child who has agreed to take part in the research. They understand that they can withdraw from the study at any time.
Children may sign the 'participant' section (above) of the form if the parent/guardian wishes.

Name of parent/guardian:

Signature of parent/guardian: _____ Date: _____

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