Brain and Cognition 68 (2008) 193–203

Contents lists available at ScienceDirect

Brain and Cognition

journal homepage: www.elsevier.com/locate/b&c

Priming vs. rhyming: Orthographic and phonological representations in the left and right hemispheres ☆

Annukka K. Lindell [a,*], Jarrad A.G. Lum [b]

[a] *School of Psychology, Brigantia Building, University of Wales, Bangor, Gwynedd LL57 2AS, UK*
[b] *School of Psychology, Deakin University, Australia*

A R T I C L E I N F O

Article history:
Accepted 18 April 2008
Available online 16 June 2008

Keywords:
Word recognition
Visual half-field
Gender
Orthography
Phonology
Left
Right
Hemisphere
Lexical

A B S T R A C T

The right cerebral hemisphere has long been argued to lack phonological processing capacity. Recently, however, a sex difference in the cortical representation of phonology has been proposed, suggesting discrete left hemisphere lateralization in males and more distributed, bilateral representation of function in females. To evaluate this hypothesis and shed light on sex differences in the phonological processing capabilities of the left and right hemispheres, we conducted two experiments. Experiment 1 assessed phonological activation implicitly (masked homophone priming), testing 52 (M = 25, F = 27; mean age 19.23 years, *SD* 1.64 years) strongly right-handed participants. Experiment 2 subsequently assessed the explicit recruitment of phonology (rhyme judgement), testing 50 (M = 25, F = 25; mean age 19.67 years, *SD* 2.05 years) strongly right-handed participants. In both experiments the orthographic overlap between stimulus pairs was strictly controlled using DICE [Brew, C., & McKelvie, D. (1996). Word-pair extraction for lexicography. In K. Oflazer & H. Somers (Eds.), *Proceedings of the second international conference on new methods in language processing* (pp. 45–55). Ankara: VCH], such that pairs shared (a) high orthographic and phonological similarity (e.g., not–KNOT); (b) high orthographic and low phonological similarity (e.g., pint–HINT); (c) low orthographic and high phonological similarity (e.g., use–EWES); or (d) low orthographic and low phonological similarity (e.g., kind–DONE). As anticipated, high orthographic similarity facilitated both left and right hemisphere performance, whereas the left hemisphere showed greater facility when phonological similarity was high. This difference in hemispheric processing of phonological representations was especially pronounced in males, whereas female performance was far less sensitive to visual field of presentation across both implicit and explicit phonological tasks. As such, the findings offer behavioural evidence indicating that though both hemispheres are capable of orthographic analysis, phonological processing is discretely lateralised to the left hemisphere in males, but available in both the left and right hemisphere in females.

1. Introduction

Generation of articulate language relies on a highly lateralised cortical network. By the mid 19th century, researchers had already concluded that when we speak, "we speak with the left hemisphere (Nous parlons avec l'hemisphere gauche)", (Broca, 1865, p. 384). This ground-breaking proposition has since been repeatedly confirmed, with increasingly sophisticated analytic techniques estimating that some 96% of right-handers have expressive language capacity functionally lateralised to the left hemisphere (Risse, Gates, & Fangman, 1997). Damage to the left hemisphere (LH) consequently produces striking linguistic deficits, involving disorders of speech production, syntactic and phonological processing. In stark contrast, right hemisphere (RH) insult produces far more subtle linguistic deficits, rarely resulting in loss of articulatory capacity. Given that the RH is increasingly acknowledged to possess significant language processing capacity (see Lindell, 2006, for review), why is the RH incapable of generating productive language?

The RH's lack of expressive language ability may relate to an inability to convert orthography to phonology, the RH being "resolutely unburdened by phonological... structure", (van Lancker, 1997, p. 2). Production of articulation necessitates phonemic recoding: if the RH cannot decode phonology, language processes associated with speech production must be mediated by the LH. Supporting evidence has been drawn from a number of differing paradigms, including clinical (e.g., Rapcsak, Beeson, & Rubens, 1991), split brain (e.g., Zaidel & Peters, 1981), and deep dyslexic research (e.g., Coltheart, Patterson, & Marshall, 1980). In the clinical realm, Chiarello and Church (1986) asked patients with LH and RH damage to make similarity judgements to visually

---

☆ This research is supported by a British Academy Grant (SG-40832) awarded to A.L.

* Corresponding author. Fax: + 44 1248 38 2599.
E-mail address: a.lindell@bangor.ac.uk (A.K. Lindell).

0278-2626/$ - see front matter Crown copyright © 2008 Published by Elsevier Inc. All rights reserved.
doi:10.1016/j.bandc.2008.04.005

presented words on the basis of rhyme, meaning, or visual similarity. Though patients with RH damage (presumably relying on the intact LH) demonstrated difficulty in matching meaning, patients with LH lesions (presumably relying on the intact RH) were particularly impaired when making rhyme judgements. Such findings are consistent with the proposition that the RH lacks the capacity to convert print-to-sound (orthography-to-phonology), and hence has difficulty determining whether two printed words sound alike.

The large body of research assessing language processing in the isolated hemispheres of split-brain patients similarly suggests a LH locus for phonological processing. Zaidel and Peters (1981) found that the isolated RHs of two commissurotomy patients were incapable of (a) matching a spelled word with a picture of a rhyming item (e.g., 'BAT' with a picture of a cat); (b) matching orthographically dissimilar rhyming words (e.g., PEA–KEY); or (c) matching orthographically dissimilar rhyming nonwords (e.g., SOTE–SHOWT). Successful performance on all these tasks requires the ability to convert graphemes to phonemes, thus such findings offer compelling evidence that the isolated RH cannot derive phonology from orthography, consistent with other split-brain investigations (e.g., Baynes, Wessinger, Fendrich, & Gazzainga, 1995; Levy & Trevarthen, 1977; Zaidel, 1978).

Like split-brain research, sodium amytal ablation (Wada technique) provides the opportunity to assess the performance of each hemisphere individually, in this case by chemically isolating the hemispheres via intra-carotid injection of the anaesthetic sodium amytal. Fedio, August, Patronas, Sato, and Kufta (1997) examined the consequences of unilateral amytal injection in 30 temporal lobectomy candidates. Whilst each hemisphere was anaesthetised, participants were asked to name a series of objects, words and nonwords. As expected, LH and RH ablation prompted neatly distinguishable patterns of errors, with LH anaesthetization prompting semantic errors and phonological alexia, and RH anaesthetization inducing visuo-perceptual mistakes. Critically, all the patients had difficulty reading nonwords when the LH was anaesthetized. By definition, nonwords lack lexical representations: reading nonwords necessarily requires the translation of graphemes to phonemes. As the isolated RH proved unable to read nonwords, Fedio et al.'s results strongly suggest that phonological processing is mediated exclusively by the LH.

Clinical, split brain and amytal ablation investigations indicate a hemispheric asymmetry in phonological processing capacity, however, comparatively little research has confirmed that this asymmetry extends to the normal population. Moreover, evidence from existing behavioural work is equivocal. Rhyme tasks have been the topic of several behavioural investigations, as determination of the 'rhyme' status of word pairs (e.g., moth–BOTH vs. moth–CLOTH) is arguably the most explicit test of phonological ability available, clearly necessitating the activation of phonological representation from visual word form. Some researchers have reported the anticipated right visual field (LH) advantage, indexing LH superiority for phonological processing.

For example, Rayman and Zaidel (1991) asked participants to determine whether pairs of orthographically dissimilar words rhymed (e.g., STONE–OWN). As anticipated, they found a clear right visual field (LH) advantage for rhyme decisions; however others have failed to replicate their finding. Crossman and Polich (1988) assessed the influence of orthographic and phonological overlap on rhyme and visual similarity decisions by orthogonally manipulating visual form (look alike: L+) and rhyme status (sound alike: S+): (L+S+) PLEA–FLEA; (L+S−) SAID–PAID; (L−S+) MAKE–ACHE; (L−S−) MIND–WALL. Surprisingly, their results indicated only a weak LH advantage for 'rhyme' decisions. Why the discrepancy in finding? It should be noted that the levels of performance accuracy in the two studies are remarkably different. Whereas Rayman and Zaidel's (1991) participants attained over 80% correct across conditions, Crossman and Polich's participants were responding at chance levels in several of the conditions. As the analyses reported rely solely on error data, a less sensitive index of performance than response latency, cautious interpretation is needed. However, beyond this caveat, there may be a less prosaic explanation.

The apparent inconsistency between the rhyme investigations may be accounted for by the influence of sex on visual field effects. Crossman and Polich (1988) found a markedly stronger hemispheric effect for male than female participants, with males demonstrating a clear LH bias for rhyme decisions. The lack of difference between left and right visual field performance for female participants thus diluted the anticipated visual field effect. The notion that there are sex differences in both cortical anatomy and activation patterns associated with language has been around for some time (e.g., McGlone, 1980), and may explain the discrepant findings.

Postmortem assessment of cortical structure indicates clear anatomical differences between male and female brains in language-related regions. For example, Harasty, Double, Halliday, Krill, and McRitchie (1997) reported evidence of sexual dimorphism in the volume of the superior temporal gyrus (including Wernicke's area) and the inferior frontal gyrus (including Broca's area), with approximately 20% greater proportional volume in these regions in female brains. Critically, the same authors found no sex difference in the proportional volume of non-language regions, such as the frontal pole. Schlaepfer et al.'s (1995) MRI research is concordant in indicating that sex differences in cortical volume are specific to language-related regions, raising the tantalising suggestion that known sex differences in cognitive function (i.e., language ability, e.g., Bakan & Putnam, 1974) may be subserved by sex differences in neuroanatomy.

Though there is some degree of contention (see Sommer, Aleman, Bouma, & Kahn, 2004, for review), recent functional imaging data suggest that sex differences in cerebral activation accompany sex differences in neuroanatomy. If females engage more distributed cortical networks during phonological processing, whereas males rely upon discretely LH lateralised neural assemblies (e.g., McGlone, 1980), distinct sex differences in patterns of brain activation during language-based tasks are anticipated. To test this hypothesis, Clements et al. (2006) compared patterns of hemispheric activation during phonological (rhyme judgment) and visuospatial (line orientation) tasks. Following region-of-interest analyses, their data indicated marked sex differences in cortical activation: males show stronger LH lateralisation in the inferior frontal gyrus during the phonological task, whereas females exhibit bihemispheric inferior frontal activation. These data confirm Shaywitz et al.'s (1995) previous report that tasks explicitly tapping phonological ability (rhyme judgment) promoted increased LH activation for male participants, but prompted a more diffuse, bilateral pattern of activation (particularly surrounding the inferior frontal gyrus) in females.

However, not all researchers have reported consistent results (see Sommer et al., 2004). Differences in finding could be partially attributable to differences in sample size, but are more likely associated with differences in the tasks administered: tasks tapping phonological processing ability have predominantly confirmed bilateral activation patterns in females, and discretely left lateralised activation patterns in males (e.g., Clements et al., 2006; Shaywitz et al., 1995). This being the case, one would anticipate reliable sex differences in behavioural performance during phonological processing tasks, with males producing a greater right visual field (LH) advantage than females, indexing more discretely lateralised control of phonological function, exactly as Crossman and Polich (1988) found.