Journal of Neurolinguistics 24 (2011) 507–520

Contents lists available at ScienceDirect

Journal of Neurolinguistics

journal homepage: www.elsevier.com/locate/jneuroling

# Functional MRI evidence for modulation of cerebral activity by grapheme-to-phoneme conversion in French, and by the variable of gender

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ARTICLE INFO

*Article history:*
Received 1 October 2010
Received in revised form 21 March 2011
Accepted 21 March 2011

*Keywords:*
Grapheme-to-phoneme conversion
Phonology
Simple
Complex
Gender
fMRI

ABSTRACT

This fMRI study aims to assess the effect of two variables on the cerebral substrate of phonological processing during visual phoneme detection: (a) the difficulty level (type) of grapheme-to-phoneme conversion (GPC, letter-sound mapping) with two modalities, simple (S) and complex (C); and (b) the gender of participants, females (F) vs. males (M). The behavioral results have shown that simple items were processed more accurately than complex ones. At the cerebral level, phoneme detection activated the left-hemisphere phonological network and several regions of this network were modulated by the GPC type. Specifically, the activity of the superior posterior temporal gyrus was significantly higher for simple grapheme detection and suggests automatic activation of phonological representations; the activity of the inferior temporal gyrus was significantly higher for complex grapheme detection, suggesting greater demands of the integrative processes for solving competitive and inhibitory processes induced by the visual and phonological properties of stimuli. With respect to gender variable, we obtained significant interaction between GPC and gender. This effect showed higher accuracy for simple graphemes in females and suggests that female participants were more proficient than males for detecting simple items. This effect suggests easier and more rapid activation of phonological codes, probably based on a specific visual strategy, different from males. This is supported by the additional activation of the lingual gyrus in females for processing simple graphemes,

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0911-6044/$ – see front matter 
doi:10.1016/j.jneuroling.2011.03.003

although the exact explanation of this effect is not clear yet and requires supplementary experimentation and evidence. Overall, our results indicate that the cognitive mechanisms and cerebral correlates of phonological processing may depend on intrinsic and extrinsic variables, such as GPC and gender.


## 1. Introduction

The phonological processes necessary for word recognition operate with phonological representations of verbal stimuli (words, pseudo-words) which can be transmitted either auditory or visually (Burton, LoCasto, Krebs-Noble, & Gullapalli, 2005). In the case of spoken (auditory) words, the phonological representations are simply accessed and automatically generated (Berent, 2008). For written words, the generation of them is less automatic and more complex, following several steps (Démonet, Fiez, Paulesu, Petersen, & Zatorre, 1996). Thus, the written units (graphemes) are first transformed into their corresponding phonemic units (sounds) (Berndt, D'Autrechy, & Reggia, 1994) which access the phonological analysis (Alario, Schiller, Domoto-Reilly, & Caramazza, 2003; Fiez, Balota, Raichle, & Petersen, 1999; Herbster, Mintun, Nebes, & Becker, 1997; Simon, Bernard, Lalonde, & Reba, 2006; Walter, Cliche, Joubert, Beauregard, & Joanette, 2001). The specific process converting graphemes into phonemes is called grapheme-to-phoneme conversion (GPC) or letter-sound (print-to-sound) translation. The GPC may be of several types. A multitude of approaches (computation, behavior, neuroimaging) indicate that the GPC type has significant effect on (a) cognitive mechanisms and strategies, and (b) the cerebral substrate of word recognition. This effect has been predicted by computational models (Ans, Carbonnel, & Valdois, 1998; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Harm & Seidenberg, 1999; Plaut, McClelland, Seidenberg, & Patterson, 1996), behavioral studies at hemispheric level (Cousin, Perrone, & Baciu, 2009; Cousin, Peyrin, & Baciu, 2006; Tremblay, Monetta, & Joanette, 2007) and neuroimaging studies at regional level (Gitelman, Nobre, Sonty, Parrish, & Mesulam, 2005; Jobard, Crivello, & Tzourio-Mazoyer, 2003). A given language is considered "transparent" (such as Italian and Spanish) if the majority of words follow regular GPC as a given phoneme corresponds to a unique grapheme. The language is "non-transparent" (such as English and French) if the majority of words follow irregular GPC (Berndt et al., 1994; Katz & Feldman, 1983; Lukatela, Popadic, Ognjenovic, & Turvey, 1980; Venezky, 2004) as a given phoneme corresponds to several graphemes, simple or complex. The GPC effect can be studied at several levels by taking into account several factors: (a) the *lexical nature* of items, words or pseudo-words (Binder, Medler, Desai, Conant, & Liebenthal, 2005; Fiez et al., 1999; Simos et al., 2002; Valdois et al., 2006), (b) the *type of the writing system*, transparent or non-transparent (Paulesu et al., 2000), and (c) the *type of print-to-sound relationship* (Cousin et al., 2009; Crossman & Polich, 1988; A. Rey & Schiller, 2005; Taraban & McClelland, 1987; Tremblay, Monetta, & Joanette, 2004, 2007; Walter et al., 2001). It has been shown that in alphabetic languages, the GPC may show supplementary variations (Rey & Schiller, 2005) such as those related to the multiple print-to-sound associations and those related to grapheme complexity. The multiple print-to-sound associations mean that one specific sequence of letters may be pronounced in different ways as one grapheme can be associated with different phonemes (Taraban & McClelland, 1987). The grapheme complexity suggests that a specific phoneme corresponds to several grapheme forms (Crossman & Polich, 1988; Walter et al., 2001). For example, the sound /o/ in French can be written using different graphemes, "o", "au" and "eau". For illustration, the French word "auto" (car) contains two /o/ phonemes. As the first position sound /o/ is written "au" ("***au***to") and the last position sound /o/ is written "o" ("aut***o***"), the correspondence grapheme-to-phoneme is variable, more difficult in former than in the latter (Crossman & Polich, 1988; Walter et al., 2001). Consequently, the GPC shows various levels of difficulty, function of grapheme complexity: According to GPC difficulty level, the stimuli may not be similarly processed and the effect of it could be reflected at both behavior and cerebral levels (Cousin et al., 2009; Perrone, Cousin, Baciu, & Baciu, 2009; Walter et al., 2001). The GPC effect has been identified behaviorally (Tremblay et al., 2007; Walter et al., 2001) and at the cerebral level in terms of variation of the degree of hemispheric specialization (Tremblay et al., 2004, 2007). Several behavioral studies that we performed previously by