PHONOLOGICAL PROCESSING DURING READING: A PRIMING STUDY IN PATIENTS WITH PARKINSON'S DISEASE

PROCESAMIENTO FONOLÓGICO EN LA LECTURA: UN ESTUDIO DE FACILITACIÓN EN PACIENTES CON ENFERMEDAD DE PARKINSON

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Abstract

In the present study, we assessed phonological priming during a visual lexical decision task (LDT) in patients with Parkinson's disease (PD). This study was performed because phonological deficiencies have been reported in patients with PD, and such processes are critical predictors of reading performance. We tested for phonological priming effects using homonyms (zarjento – SARGENTO), where the prime differed from the target orthographically but with complete phonological overlap, and rhymes (cadera – MADERA), where the last two syllables of both the prime and the target are identical. Both types of priming were compared to the non-rhyme baseline condition (mercader – CUCHILLA) to assess the size of the priming effect. The results indicated that patients with PD exhibited a smaller phonological priming effect than controls in the homophonic condition. Patients with PD also displayed a lower percentage of correct responses and longer Reaction Times (RTs) than controls on both rhyme and homophone pairings. No group differences were found in the non-rhyme experimental condition. We concluded that phonological processing in patients with PD is important for lexical access during visual word recognition.
Keywords: Phonological priming, Parkinson's disease, visual word recognition, reading, rhyming.

Resumen

En el presente estudio se evaluó la facilitación fonológica durante una tarea de decisión léxica visual (LDT) en pacientes con enfermedad de Parkinson (EP). Este estudio se realizó debido a que se han reportado deficiencias fonológicas en pacientes con EP lo que es indicativo del desempeño en la lectura. Analizamos los efectos de facilitación fonológica utilizando pares de palabras homónimas (zarjento - SARGENTO), donde el facilitador y el blanco difieren ortográficamente, pero tienen una completa superposición fonológica, y pares con rimas (cadera - MADERA), donde las dos últimas sílabas del facilitador como del blanco son idénticas. Ambos tipos de pares de palabras se compararon con condición de línea base de no rima (mercader - CUCHILLA) para evaluar la magnitud del efecto de facilitación. Los resultados indicaron que los pacientes con EP exhibieron un menor efecto de facilitación fonológica que los sujetos control en la condición pares homófonos. Los pacientes también mostraron un menor porcentaje de respuestas correctas y mayores tiempos de reacción (TR) que en los controles, tanto en los pares con rima y homófonos. Concluimos que el procesamiento fonológico en pacientes con enfermedad de Parkinson es importante para el acceso léxico en el reconocimiento visual de palabras.
Palabras clave: Facilitacion fonológica, enfermedad de Parkinson, reconocimiento visual de palabras, lectura, rima.

Introduction

Parkinson's disease (PD) is a syndrome characterized by involuntary resting tremors, muscle rigidity and a slowness of movement. These symptoms are due to a significant decrease in dopamine levels resulting from dysfunction of the substantia nigra. The substantia nigra is composed of the dopamine-containing pars compacta and the pars reticulate. The substantia nigra is critical to basal ganglia function. Degeneration of dopamine-synthesizing neurons in the pars compacta has been linked to PD and related disorders (Graybiel, 2000). Although the primary deficiencies observed in patients with PD involve motor skills, recent clinical research has also demonstrated the presence of cognitive deficits. These deficits include decreased executive functions (Cameron, Pari, Alahyane, Brien, Stroman, et al., 2012; Grossman, Cooke, Devita, Lee, Alsop, Detre, et al., 2003), impaired attention and working memory (Ell, Weinstein, & Ivry, 2010) and impaired processing of sequential information (Hikosaka, Nakahara, Rand, Sakai, Lu, Nakamura, et al., 1999). Language deficiencies have also been reported in patients with PD. In a review of speech timing, Schirmer (2004) provided evidence that patients with PD exhibit problems in speech perception and pro-duction. These patients also exhibit difficulties with tasks involving resolution of ambiguous words (Chenery, Angwin & Copland, 2008) and semantic priming (Copland, 2003). Patients with PD exhibit poor complex sentence comprehension (Angwin, Chenery, Copland, Murdoch & Silburn, 2005), deficits in verb generation (Crescentini, Lunardelli, Mussoni & Shallice, 2008), and difficulties with understanding the meanings of metaphors (Monetta & Pell, 2007). PD patients also exhibit grammatical problems that are similar to those of patients with agrammatic Broca's aphasia (Bastiaanse & Leenders, 2009).

The dopaminergic dysfunction that is characteristic of PD results from basal ganglia (BG) dysfunction. The nuclei of the BG, together with the cortex and the thalamus, are essential components of a canonical neural macro-circuit. The normal function of such macro-circuits requires that each of the circuit's components is functioning properly. Because of the parallel and circular organization of BG circuits, these nuclei are involved in the reconfiguration of cortical activity patterns. That is, the macro-circuit collects and concentrates cortical information in the BG and then projects this processed information back to the cortex via

the thalamus (Kotz, Schwartze & Schmitt-Kassow, 2009). Thus, studies of PD implicate the BG not only in motor behavior but also in language and cognition.

Although the role of the BG in language remains controversial, there is significant evidence for their involvement in the perception of rhythm (Grahn & Brett, 2008) and sound (Kotz et al., 2009). In fact, the mammalian telencephalic BG-thalamic circuit is equivalent to the avian sensorimotor circuit that allows for the production and proper perception of bird song (Brenowitz, Perkel & Osterhout, 2010). The relationship between perception and speech production and activity in the BG is further supported by evidence that "the BG are critically involved in building up sequences of behavior into meaningful, goal-directed repertories" (Graybiel, 1995). The BG pattern generators operate as neural activity organizers underling action-oriented cognition in a manner analogous to how the motor system generates cognitive patterns (Graybiel, 1995; 2005). The motor theory of speech argues that both speech perception and production rely on articulatory gestures in that auditory and motor representations are already phonetic (Liberman & Whalen, 2000). This theory further argues that letters correspond to articulatory gestures and that reading involves the activation of these representations.

Several studies have indicated that the striatum is involved in the application of linguistic rules (Vannest & Lewis, 2005; Teichmann, Dupoux, Kouider, Brugieres, Boissé, Baudic, et al., 2005), including the morphosyntactic processing of word flexions (i.e., walk – walked; Ullman, 2001). According to the procedural / declarative model, language is processed by two separate memory systems: a rule application or procedural system and an association memory system (Ullman, 2001). The fronto-striatal procedural system allows for the use of compositional principles that govern the assembly of morphemes and phonemes into higher order units, such as words, sentences and phrases. Teichmann, Gaura, Demonet, Supiot, Delliaux, Verny et al. (2008) have suggested that the ventral portions of the striatum may be involved in linguistic rule application given that these regions receive information from cortical areas (e.g., Broca's area) that have been implica-

ted in adherence to these rules (Ullman, 2006). In contrast, the dorsal portions of the striatum are more likely to perform lexical operations, given that this region receives information from the temporal cortices (Middleton & Strick, 1996). Recently, a direct relationship between the BG and phonological processing has been demonstrated. A PET study revealed that phonological processing accuracy in healthy individuals is correlated with caudate dopaminergic activity and that phonological processing speed is correlated with activity in the left putamen (Tettamanti, Moro, Messa, Moresco, Rizzo, Carpinelli et al., 2005). Furthermore, the phonetic perception of pseudowords and nonwords increases the firing rate of striatal cells (Abdullaev & Melnichuk, 1997).

Considering the involvement of the BG in phonological processing, it follows that patients with PD would exhibit problems in visual word recognition and sentence processing. Determining the relationship between PD and phonological processing will also aid in understanding the role cortico-subcortical circuits play in reading processes. Furthermore, these results will likely increase our understanding of BG involvement in reading disorders. Reading disabled subjects have been reported to exhibit poor reading performance due to deficient phonological processing (Ramus, 2003; Silva-Pereyra & Rivera-Gaxiola, 2005). Both patients with PD (Schirmer, 2004) and those with reading disorders (Helenius, Uutela & Hari, 1999) have difficulty processing rapid sound sequences. According to the dual-route model (Coltheart, Rastle, Perry, Langdon & Ziegler, 2001), written words can be read either a) sub-lexically (based on grapheme-phoneme correspondence) to allow for the reading of unfamiliar words and pseudowords, or b) lexically, a process that allows for the reading of familiar and irregular words. Developmental reading disorders are generally discussed within this framework (Coltheart et al, 2001; Castles & Coltheart, 1993). It is believed that individuals with reading disorders have phonological processing deficits. This deficiency may explain the inefficient word decoding observed in reading impaired individuals. Phonological processing has been identified as a problem in dyslexia (Ramus, 2003). Phoneme segmentation and awareness tasks can differentiate good and

poor readers, as can measures of rhyming skill. These measures may serve as valid predictors of future reading ability (Snowling, 2000).

During reading, the use of a phonological code is important for visual word recognition. Previous cognitive psychology research has studied the role of phonological information in silent reading (Carreiras, Ferrand, Grainger & Perea, 2005). To examine the influence of phonological processing during lexical access, many researchers have utilized priming tasks (Carreiras, Perea, Vergara & Pollatsek, 2009). Priming is a form of implicit memory that results in a change in the speed or accuracy of stimulus processing when that stimulus is preceded by a related stimulus (Wilson, Tragellas, Slason, Pasko & Rojas, 2010). Phonological priming during reading consists of the extraction of phonological information from the "prime" stimulus, facilitating the recognition of a related and subsequently presented "target" stimulus. Using lexical decision tasks, a number of studies have shown that the presentation of a homophonic prime (e.g., rait) decreases response times to the target stimulus (e.g., RATE) more than orthographic controls (e.g., raut) (Rastle & Brysbaert, 2006). The lexical decision task assumes that the homophone and the orthographic control are equally similar to the target. Although the control and homophone primes are matched to the target stimulus on a number of variables, including the number of letters and word frequency, it is usually not possible to control all factors, including the visual letter similarity.

The aim of the present study was to evaluate phonological priming in PD patients during word reading. In this study, the participants performed a lexical decision task wherein they decided if the second word in each prime - TARGET pair was a real Spanish word. Given the phonological demands of reading, PD patients were expected to perform poorly on LDTs that involve phonological priming, such as word - WORD or pseudoword - WORD pairs that rhyme or sound identical (i.e., homophonic). Rhyming word primes shared four of their six letters with the target word and the final two syllables of both the prime and target words were identical (e.g., madera – CADERA). Homophone primes were pseudowords that shared five of their eight letters with the target

word and complete phonological overlap (e.g., eztreya – ESTRELLA). Non-Rhyme primes shared no letters (in any given position) with the target word (mercader – CUCHILLA). We hypothesized that PD patients would display a weaker phonological priming effect (i.e., faster RTs and a higher percentage of correct responses in the Homophonic and Rhyme conditions than in the Non-Rhyme condition) than Control group due to phonological deficiencies present in the PD group. This difference is predicted to be maximal for homophone pairs where the phonological overlap is complete.

Method

Participants
At the onset of testing, each participant received an explanation of the study and provided informed consent, in accordance with the Helsinki Declaration guidelines (Declaration of Helsinki, 2008). Additional health history information was obtained from all of the participants using a semi-structured interview. This information was used to identify inclusion and exclusion criteria. All participants were evaluated using a Spanish version of the "Edinburgh Handedness Inventory" (Oldfield, 1971), which is included in the brief version of the Barcelona Test (a-TB, Peña-Casanova, Guardia, Bertran-Serra, Manero & Jane, 1997). This inventory assesses handedness on 10-items using a scale of 1 to 5. Subjects were classified as right handed (summed scores between 10 and 20) or left handed (scores between 40 and 50). This assessment is important because of the left lateralization of language. Moreover, an equal number of right-handers and left-handers were included in each group (Table 1).

Parkinson's disease Group
Patients with PD were recruited from the "Hospital Central Militar" in Mexico City. These patients were identified at the time of this study and were invited to participate by two consulting neurologists who specialized in movement disorders. The participants were required to meet the following inclusion criteria: a) a diagnosis of idiopathic Parkinson's disease, with an assessed disease stage between Hoehn & Yahr stages I and

II (Hoehn & Yahr, 1967); b) Spanish as the native spoken language; and c) self-reported normal or corrected-to-normal hearing and vision, verified by the examiner. The patients were excluded if they had a) a history of severe head injury, stroke, diagnosis of dementia, or other neurological impairment; b) a major medical or psychiatric illness requiring hospitalization; or c) clinical depression or a major depressive episode in the previous six months. Patients were assessed using the Unified Parkinson's Disease Rate Scale (UPDRS), Section I: Mentation, Behavior and Mood. The focus of this assessment was on point 3 "Depression" and point 4 "Motivation/Initiative." All patients were tested while on anti-parkinsonian medication (Table 1). The results of the UPDRS show that under the influence of medication, the patients were not significantly impaired. The final study sample consisted of 15 patients with PD. All patients were taking similar anti-parkinsonian medications. All patients presented with tremor and rigidity. Symptom onset was on the right side in eight patients and on the left side in seven patients.

Control Group

Fifteen healthy controls were recruited on the basis of age, gender, and educational/socioeconomic levels to match the PD Patients. The Control Group was recruited from a previously established database of health service recipients or from the patients' relatives. At the time of recruitment, the Control Group was given a brief outline of the study followed by a detailed information sheet if they were willing to participate. In addition to normal or corrected-to-normal hearing and vision and being between 50 and 80 years of age, the exclusion criteria listed above also applied to the Control Group.

Table 1.
Demographic characteristics of the participants. Mean and Standard deviation (SD)

PD Group

Age (years)	Gender	Years of Education	Disease Duration (years)	Pharmacological Treatment	UPDRS	Lat	LOS
61.2 (9.5)	F/M 5/10	8.0 (2.17)	4.9 (3.4)	Levodopa-Carbidopa, Rasagiline, Pramipexole.	15 (2.2)	10.4 (.83)	L/R 7/8

Control Group

Age (years)	Gender	Years of Education	Disease Duration (years)	Pharmacological Treatment	UPDRS	Lat	LOS
61.2 (9.5)	F/M 5/10	8.2 (2.14)	---	---	---	10.4 (.73)	

Lat (Laterality; Edinburgh Inventory, max = 10, right handed).
LOS (Laterality of the onset of symptoms; L, Left: R, Right)
M, male; F, female.

Stimuli

Seven hundred nouns were selected from the LEXESP computerized database of the Spanish Language (Sebastian, Marti, Cuetos & Carreiras, 1996) and from a corpus of Mexican Spanish words (Lara, Ham-Chande & García-Hidalgo, 1980). Nouns that could also be used as verbs were excluded from the word set. All stimuli were six or eight letter Spanish singular nouns with three syllables and were matched according to word frequency (mean word frequency of 19 appearances/million words, SD 37.5).

Syllables from the word set were then recombined to generate five hundred pseudowords. All pseudowords were pronounceable in Spanish and had similar word characteristics with respect to phonology (e.g., number of syllables, syllable frequency, and consonant–vowel structure).

To create 300 prime-target pairs, words and pseudowords were grouped according to the type of word pair and whether they rhymed, as shown in Table 2. No significant differences in prime-target pair lexical properties were present across experimental conditions. Specifically, frequency of occurrence ($F_{(2,297)} = 1.7$, $p = .2$), phonological frequency of the first syllable ($F_{(2,277)} = 1$, $p = .4$), phonological frequency of the second syllable ($F_{(2,274)} = .3$, $p = .7$), and phonological frequency of the last syllable ($F_{(2,277)} = 1$, $p = .4$) were compared. Between experimental conditions, stimuli did not differ on orthographic frequency of the first syllable ($F_{(2,274)} = .7$, $p = .5$), orthographic frequency of the second syllable ($F_{(2,274)} = .07$, $p = .9$), or orthographic frequency of the last syllable ($F_{(2,274)} = .7$, $p = .5$).

Three hundred prime-target letter string pairs were built by pairing words with pseudoword targets. Two types of pseudoword pairs were created: word - PSEUDOWORD (both rhyming and non-rhyming pairs) and pseudoword - PSEUDOWORD (non-rhyming).

Finally, the 600 letter string pairs were divided into two experimental lists. Each list consisted of 50 word pairs per condition. The conditions were evenly divided such that 50% of the targets were words and 50% were pseudowords; moreover, 50% of the stimuli were phonologically related.

Procedure

Lexical decision task.

The stimulus pairs were presented in a random order using the STIM software TM package (NeuroScan, Inc.). Stimuli were presented on a 36 cm PC LCD monitor. Figure 1 illustrates the temporal sequence of the stimulus presentation. Each trial consisted of the following elements: (1) a fixation point (an asterisk) was presented in the center of the screen for 500 ms; (2) a dark screen was presented for 100 ms; (3) a "prime" letter string was presented at the center of the screen for 500 ms; (4) a dark screen was presented for 100

Table 2.
Experimental conditions and examples

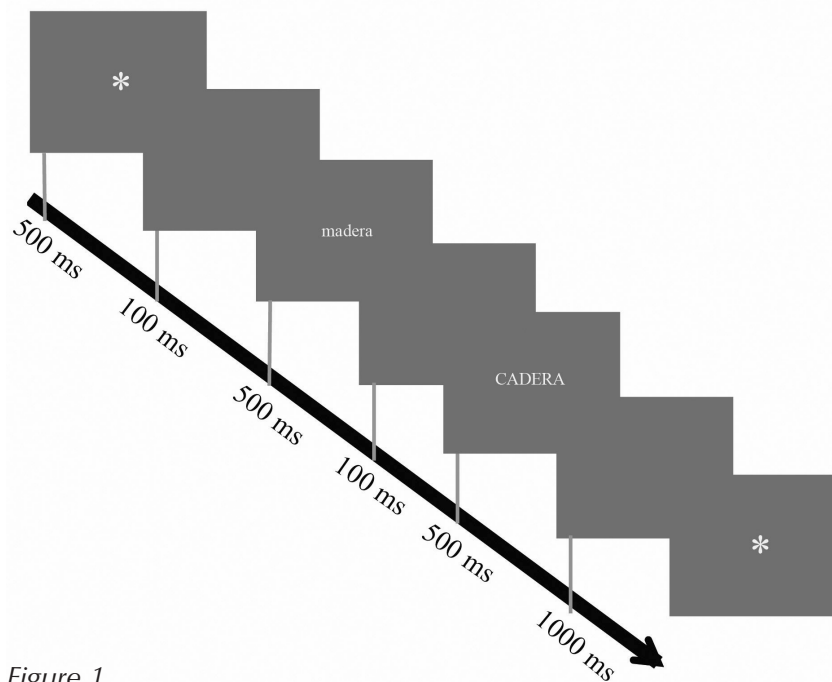|	Type of pair word (pseudoword) / WORD
Rhyme	madera / CADERA
Homophones	zarjento / SARGENTO
Non-Rhyme	canela / PELOTA

Figure 1.
The stimulus presentation sequence.

ms; and finally (5) a "TARGET" letter string was presented at the center of the screen for 500 ms. The stimulus onset asynchrony (SOA) was 600 ms. The inter-trial time interval was 1000 ms. The participants were instructed to press one button on the computer mouse when the target stimuli were real Spanish words and a different button if they were not. Patients with PD answered with the hand on the less affected side, as determined by the neurological evaluation. For the control group, the designation of the mouse buttons was counterbalanced across the subjects.

To counterbalance stimulus presentation, half of the controls and PD patients were assessed using the first word pair list, and the other half of participants were assessed using the second list. Correct and incorrect responses were automatically recorded. To exclude priming effects due to pre-lexical visual associations, the primes were presented in lowercase and the target stimuli were presented in uppercase letters. The prime words were displayed in lowercase letters 1 cm tall, and the target words were presented in uppercase letters 1 cm tall. Both letter sets were presented in the center of the computer monitor. The visual

angle of stimulus presentation was approximately 4.584° X 0.573°. Each participant received a 10 trial training phase prior to the experiment. The training stimulus word pairs were not used in the experimental trials.

Data analysis
The mean reaction times (RT) for correct responses were calculated for each participant. These data were analyzed using a mixed-design 2-way ANOVA with one within-subjects factor (Experimental conditions: Rhyme, Non-rhyme and Homophone) and one between-subjects factor (Groups: PD Group and Control Group). The Huynd-Felt correction was applied when the numerator of the degree of freedom was 2 or greater.

The percentages of correct responses were transformed using the ARCSIN [SQRT (percentage/100)] function in Excel. A 2-way ANOVA was performed on the transformed percentage values in a manner similar to the RT data analysis. When necessary, post-hoc Tukey tests were performed. Only interactions and main effects of group are reported.

Results

Reaction Times

Participants in the Control Group made lexical decisions faster than patients with PD (main effect of Group: F (1,28) = 4.3, p = .05, ηp2 = .1). A statistically significant Condition by Group interaction (F (2,56) = 5.4, p = .01, ε = .7, ηp2 = .2) was observed. Post-hoc analyses revealed no significant phonological priming effect (word - WORD Rhyme versus Non-Rhyme conditions) in the Control Group (MD = 7.6, p = .5). A marginal phonological priming effect was observed in PD patients (MD = 23.5, p = .05). The phonological priming effect was significantly greater in controls (MD = 141, p < .001) than in PD patients (MD = 54.8, p = .02) for pseudoword - WORD Homophone versus word - WORD Non-Rhyme comparison.

Further post-hoc analyses revealed significantly faster responses in control subjects compared to PD patients in the word - WORD Rhyme condition (Tukey HSD, mean difference (MD) = -86, p = .08) and in the pseudoword -WORD Homophone condition (MD = -156.4, p = .01). No group differences were found for the word - WORD Non-Rhyme condition (MD = -70.3, p = .1).

Percentage of correct responses

The results indicated that controls made a higher percentage of correct responses than PD patients (main effect of Group: F (1,28) = 15.4, p = .001, ηp2 = .4). The percentage of correct responses tended to be higher in the rhyming conditions for control subjects than PD patients (Condition x Group interaction F (2,56) = 2.5, p = .09, ε = 1, ηp2 = .1). No phonological priming effect (greater percentage of correct responses to word - WORD Rhyme than Non-Rhyme conditions) was observed in the Control Group (MD = .04, p = .3); however, a marginal priming effect was observed in PD patients (MD = -.1, p = .08). In contrast, a significant phonological priming effect was observed for pseudoword - WORD Homophone versus word - WORD Non-Rhyme in controls (MD = -.1 p = .06) but not in PD patients (MD = .2, p = .7). Overall, control participants exhibited a higher percentage of correct responses than PD patients on the word - WORD Rhyme (MD = .2, p < .001) and pseudoword - WORD Homophone (MD = .2, p < .001) conditions.

Discussion

To evaluate the degree of phonological priming in word reading, patients with PD performed a lexical decision task. We hypothesized that, compared to controls, patients with PD would show weaker phonological priming effects (i.e., faster and a higher percentage of correct responses in the Rhyme and Homophonic conditions than in the Non-Rhyme condition). These group differences were predicted to be more evident when the phonological overlap between prime and target involved the whole word (i.e., pseudoword - WORD homophone pairs).

The results partially support our hypotheses. Although patients with PD showed a weaker phonological priming effect than controls in the Homophonic condition (compared to the Non-Rhyme condition), PD patients showed marginal priming effects in the Rhyme condition. In contrast, the controls did not show a phonological priming effect in the Rhyme condition. The results also indicated that PD patients made fewer correct responses and took longer to respond than controls when presented with Rhyme and Homophone pairs. No between-group differences in the Non-Rhyme experimental condition were observed, indicating that PD patients are not globally impaired on this task, relative to controls.

The results could imply that PD patients have deficiencies in phonological processing only when lexical processing is involved. This is because PD patients showed weak or no significant phonological priming effect to homophonic experimental condition (where the prime was a pseudoword). Although phonological codes are necessarily activated during verbal word reading, silent reading could also be performed using phonological information. The phonological mediation hypothesis (Frost, 1998) suggests that semantic access depends on phonological activation. Therefore, word phonology would typically be computed before word meaning is accessed (Humphreys, Evett & Taylor, 1982). According to this view, phonological activation occurs automatically during reading and should take place relatively early in the process of visual word recognition.

When words are read aloud, phonological processing is performed relatively late, after the
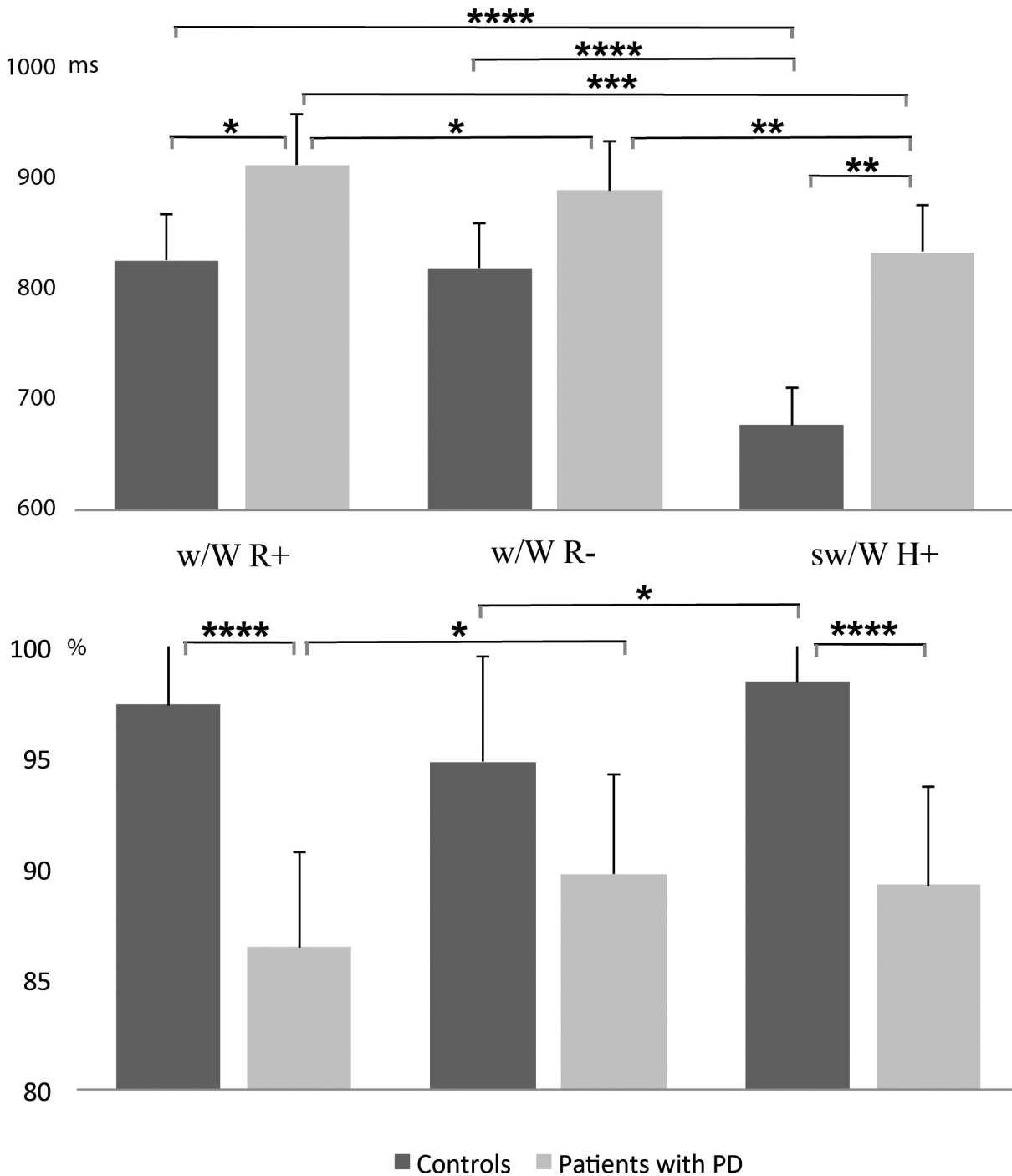
Figure 2. (Top) Mean RT values from the Group by Condition interaction. Patients with PD had longer RTs in the Rhyme and Homophonic conditions.

(Bottom) Mean of the percentage of correct responses in the Group by Condition interaction. Significant differences are indicated. Task conditions included: the word - WORD Rhyme condition (w/W R+), the word - WORD Non-Rhyme condition (w/W R-), and the pseudoword - WORD Homophonic condition (sw/W H+). * p < .08, ** p < .05, *** p < .01, **** p < .001

meaning is accessed (Seidenberg, 1985). This hypothesis is consistent with results from studies using language generation tasks to examine the activation of subcortical regions involved in semantic and phonological processing. In these studies, the left pre-SMA, the area adjacent to Brodmann's area 32, the left dorsal caudate nucleus and adjacent capsule, and the ventral anterior thalamus were all activated during the retrieval of pre-existing lexical items, whether the tasks were based on semantic or phonological processes. However, a very small portion of the pre-SMA is activated during nonsense syllable generation (Crosson, Benefield, Cato, Sadek, Moore, Wierenga, et al., 2003). It is believed that SMA-caudate-thalamus loop activity during word generation is related to maintaining a bias toward the retrieval of a single lexical item, rather than choosing between competing alternatives. Relatively widespread activity in the right BG during the generation of lexical items may be driven by input from the left pre-SMA and may be responsible for preventing right frontal structures from interfering with language generation (Crosson et al., 2003).

However, an automatic early influence on phonological information in visual word recognition has been observed during silent reading, which is most likely performed during the lexical decision task (Braun, Hutzler, Ziegler, Dambacher & Jacobs, 2009). In fact, previous imaging studies have proposed that the SMA is part of Baddeley's Phonological Loop (Baddeley, Gathercole & Papagno, 1998). In that model, activity in the inferior frontal gyrus (IFG) is linked to articulatory rehearsal and activity in the supramarginal gyrus (SMG) is linked to phonological storage (Gold & Buckner, 2002). The SMA receives projections from the caudate nucleus (Graybiel, 1995; Maddox & Ashby, 2004) and is active during tasks that involve the retrieval of pre-existing lexical items. Printed words likely activate the interface between the orthography and phonology systems, allowing for the mapping of orthographic representations onto their corresponding phonological representations. Thus, patients with PD, who have a compromised procedural-system, exhibit poor performance on phonological tests that require visual word recognition.

Phonological deficiencies alone do not account for the low reading performance observed in PD patients and other hypotheses should be considered. Individuals with reading disorders also exhibit slower spatial attention shifts, which may explain the inefficient multisensory processing of perceptual stimuli (Hari & Renvall, 2001). Generally, it is assumed that the sub-lexical route requires a primary process of graphemic analysis, which is the visual segmentation of a chain of graphemes into its constituent parts (Perry, Ziegler & Zorzi, 2007). Therefore, it is clear that sub-lexical phonological assembly involves both rapid and accurate visual processing as attention is shifted to each isolated grapheme. In addition, the appropriate phonological characteristics of the graphemes must be processed. Thus, the low reading performance observed in PD patients may be the result of deficiencies in a visual segmentation system that transform visually encoded information into a language code. According to Maddox & Ashby (2004), the entire extrastriate visual cortex projects directly to the tail of the caudate nucleus. Medium spiny cells in the tail of the caudate nucleus project to the prefrontal and premotor regions of cortex. Specifically, they project to the supplementary motor area (SMA) via the globus pallidus and the thalamus. Thus, it is assumed that each unit of the caudate undergoes a procedural learning process and serves as a link between a large group of visual cortical cells inputs and an abstract motor program that is most likely represented in the SMA. In this circuit, visual sequence stimuli (i.e., letter or word strings) are processed during reading in a manner compatible with the concept of an orthographic code being translated into a phonological code and a motor plan during reading aloud. The BG is also involved in oculomotor control processes associated with reading (Graybiel, 1995). Kermadi and Joseph (1995) demonstrated that many neurons in the caudate nucleus of highly trained monkeys code for learned sequences of eye-hand movements. These neurons responded to sequentially presented sensory cues and the movement-related responses were sequence-dependent.

The anti-parkinsonian medication used by the patients in this study can be assumed to have a

general, beneficial cognitive effect. We hypothesized that patients with PD would show a smaller phonological priming effect than controls. Anti-parkinsonian medication may improve phonological processing in PD patients, given that the phonological priming difference between groups was not disproportional. Indeed, in a study of PD patients that assessed the effects of three months of rasagiline treatment on different cognitive domains (including language), beneficial effects on aspects of attention and executive functions (e.g. verbal fluency) were reported (Hanagasi, Gurvit, Unsalan, Horozoglu, Tuncer, Feyzioglu, et al., 2011). Thus, on-off studies with anti-parkinsonian medication are needed to determine the functional role of dopamine on phonological processing in patients with PD. A possible role for dopamine in phonological processing could be speculated given both the nature of the above-mentioned circuits (centered on the BG) and the fact that recent studies linked this neurotransmitter to phonological processing. Tetamanti et al. (2005) reported a correlation between phonological processing accuracy and caudate dopaminergic activity. That study also reported a correlation between phonological processing speed and activity in the left putamen of healthy individuals.

Conclusion

The results of the present study suggest that the weak phonological priming effect observed in patients with PD is probably the result of altered phonological processing that affects the visual word recognition. Functional disturbances in the BG and cortico-subcortical circuits in these patients may underlie the disruption of phonological processing during reading.

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