Auditory ERP in Extremely Premature 5-Year-Old Children

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The aim of this research was to test the hypothesis of a functional impairment in the automatic detection of deviant tones in 141 children born after 25 to 28 weeks of gestational age, as compared to 45 age-matched full-term control children. All of them were assessed at age 5 years 9 months and instructed to listen passively to two different pure tones (1000 vs 1200 Hz; 20 vs 80%) counterbalanced between ears. Rarity was thus defined by specific ear by tone combinations. The temporal N100 showed a clear contralateral functional organization of the central auditory pathway, especially for the left ear, but without group difference. By contrast, in full-term controls but not in premature children, the central N200 was specifically increased over frontal leads to rare stimuli as compared to frequent. Premature children demonstrated a lack of brain response when more complex processing integrating different informations was required.   © 2002 Elsevier Science (USA)

INTRODUCTION

Advances in medical technology have brought remarkable improvements in the mortality rates of prematurely born infants. For example, the average survival rate of infants born between 23 and 26 weeks gestational age reached 60% in the 1980s (Whythe et al., 1993, Lefebvre et al., 1996). However, this therapeutic success was accompanied by a significant incidence of major sequelae during early childhood, such as cerebral palsy, mental retardation, and vision or hearing loss. Incidence of such sequelae varied from 17 to 38% in recent cohorts of surviving premature infants. In addition, long-term morbidities at preschool and school age have been documented. Between 5 and 12 years, IQs were significantly lower in very premature children than in matched controls, albeit generally in the normal range, and showed a greater variability between items (for a review, see Orstein et al., 1991). The premature children often demonstrate learning and academic problems (ranging from 57 to 60%), inattentive and hyperactive behavior (16 to 19%), language delay and articulation deficits, and 9 to 24% of them required special education (Szatmari et al., 1990; Hack et al., 1994). Subtle difficulties, such as fine motor delay, visuo-motor integration deficits, or poor balance and coordination become more apparent over time and might only be diagnosed at school age when they impair handwriting learning.

Evoked Potentials have been used to define the brain functional alterations in preterm babies, for example to assess brain processing of pure tones (Kurtzberg et al., 1984). When they reached 40 weeks post-conception age, premature infants had a higher proportion of immature response than the normal full-term babies, but this maturational delay was corrected at three months of age. However, deficits in more complex auditory processing might be present later in development. We already showed (Lavoie et al., 1998) that the topographical distribution of the visual P3b was different in healthy 5-year-old premature children compared with matched controls. In this study, we aimed at testing the hypothesis that a functional impairment in the automatic detection of deviant tones may still be manifest at this age, by using a very large sample of extremely premature children. At 5–6 years of age, the brain response to auditory stimuli is mainly formed by a temporal negativity (N100) fol-

lowed by a fronto-central negativity (N200) which is likely to be related to orienting reaction. As these two brain responses seem to correspond to different levels of information processing, our specific hypothesis was that the long latency fronto-central processes are more affected than the earlier temporal processes in premature children.

METHOD

Subjects

In Ste. Justine hospital, at gestational ages between 24 and 28 weeks, 254 infants, out of 364 (70%) admitted to the neonatal intensive care unit, survived between the years 1987 to 1992. A sample of 141 children aged 5 years 9 months represents our premature subjects while 45 controls born at term were recorded at precisely the same age. The clinical characteristics of the subjects are presented in Table 1.

EEG Recordings

EEG was recorded from 14 electrodes placed according to the 10–20 System (Jasper, 1958) at Fz, Cz, Pz, Oz, F8, F7, C3, C4, T3, T4, P3, P4, T5, and T6. All electrodes were referenced to linked earlobes and their impedance was kept below 5 Kohms. The horizontal EOG the electrodes were placed at the outer canthus of each eye and for the vertical EOG infra- and supraorbital to the left eye. The EEG signal was amplified with a bandpass between 0.1 and 30 Hz and corrected for EOG artifacts in the frequency domain (Woestenburg et al., 1983). Before EOG correction, all EOG epochs with a clipping duration longer than 100 ms were rejected. The sampling started at 72 ms before the stimulus onset until 440 ms after stimulus onset, and the epochs were averaged time-locked to the stimulus. Digital filtering was done offline (0.25–10.64 Hz at 3dB, 0.20–12.77 Hz at 12 dB).

TABLE 1
Clinical Data at 5 Years Old

Group	Premature (n = 141)		Full term (n = 45)		P value
	Mean	SD	Mean	SD	
Age (months)	69.8	1.6	69.6	1.2	ns
Gestation time (weeks)	27.3	1.2	39.5	1.5	<.001
Birth weight (g)	1009	219	3464	373	<.001
Male/Female ratio	70/71		16/29		
Apgar 1	4.6	2.6	8.2	1.7	<.001
Apgar 5	6.4	2.4	9.1	0.8	<.001
Apgar 10	7.3	2.0	9.6	0.5	<.001
General Cognitive Index[a]	98.0	19.4	115.3	12.7	<.001
Family adversity score (5 years)[b]	0.2	0.2	0.1	0.2	<.001
Neurological Impairment (%)					
None	70		100		
Light-moderate	16		0		
Severe	8		0		
Missing	6		0		

[a] McCarthy Scales of Children's Abilities (1972).
[b] Family Adversity Scale (Vitaro et al., 1992).

Procedures and Instruments

The passive auditory task consisted in a sequential presentation of 300 tones to each ear with a fixed presentation time of 20 ms (rise-fall time 2 ms), equally divided into 2 tones of 80 db SPL. For the right ear, a 1200 Hz tone constituted a locally rare stimulus ($n = 30$) was and a 1000 Hz tone the locally frequent stimulus ($n = 120$). Conversely, for the left ear, the 1000 Hz stimulus was locally rare ($n = 30$) and the 1200 Hz stimulus was locally frequent ($n = 120$). Specific averaging were obtained, separately for each ear, for all the rare trials and for 30 frequent stimuli selected among the 120 presented so that they did not differ from the 30 corresponding targets with regard to the length of the preceding standard tones. The interstimulus interval varied quasi-randomly between 550 and 950 ms.

Statistical Analyses

For each trace, the baseline-to-peak amplitude and peak latencies from stimulus onset were determined separately. The amplitude and the latency of a temporal N100 was measured as the most negative point between 83 and 273 ms on the temporal electrodes (T3/4) where it was maximum, yielding only 6.3% of missing value that were measured manually. N200 was maximum centrally and its amplitude and latency were measured on F7/8, C3/4, and P3/4 between 190 and 360 ms, with 5.2% of manual measures. There was one between-groups factor (premature/control: GROUP) and three within-subject factors (1000/1200 Hz: TONE, rare/frequent: CONDITION and left/right: EAR). It should be noted that a EAR by TONE interaction is a condition effect. The hemisphere (HEMI) and leads (LEAD) constituted additional within-subject factors. In all analyses the significance level was set at 5% (two-tailed) with Greenhouse–Geisser (1958) corrections for degrees of freedom. When the lead factor was included in a significant interaction, we normalized the data in order to distinguish a difference in shape of the ERP wave from a distance effect across different leads (McCarthy & Wood, 1985).

RESULTS

The Temporal N100

N100 latency was significantly shorter on the electrode contralateral to the stimulated ear (EAR by HEMI: $F(1, 184) = 42,30, p < .001$). This faster response of the contralateral hemisphere was found for left ear (4 ms; HEMI: $F(1, 185) = 5,27$, $p < .05$) as well as for the right ear (13 ms; HEMI: $F(1, 185) = 51,45, p < .001$). However, this effect was not related to group, and no main group differences was noted. This faster response on the site contralateral to the stimulated ear was accompanied by an increased amplitude (EAR by HEMI: $F(1, 184) = 7,05, p < .01$). This amplitude enhancement tended to be significant for the left ear (0.7 µV; HEMI: $F(1, 185) = 2,96, p = .09$) and nearly reached significance threshold for the right ear (0.8 µV; HEMI: $F(1, 185) = 3,54, p = .06$). Moreover, a complex tone by ear by hemisphere interaction ($F(1, 184) = 5,23, p < .05$) revealed that a larger response (+1.7 µV) was elicited by the 1000 Hz tone, as compared with the 1200 Hz tone, when it was presented on the left ear and recorded on the right temporal site ($F(1, 185) = 7.64 \ p < .01$). This increase was only of 1 µV and nonsignificant for the 1000 Hz tone presented to the right ear and recorded in the left temporal site. The left ear-right hemisphere path was thus facilitated for the detection of the deviant

tones, but again no group difference and no interaction with group was found for the N100 amplitude measurements.

The Central N200

In striking contrast with the temporal N100, all the differences found for the N200 component included the group factor. A group by hemisphere by electrode interaction ($F(2, 368) = 4.43$, p $< .05$; X $= .93$) showed that in the control group, the N200 recorded on the right hemisphere peaked first over the frontal electrode (263 ms), then over the central (269 ms), and finally over the parietal sites (274 ms). By contrast in preemies, N200 reached its maximum on the parietal electrodes (266 ms) before it peaked on the central (267 ms) and the frontal sites (270 ms). As a result, the group difference was significant on the right parietal lead ($F(1, 104 = 5.55, p < .05$). These difference were still significant after normalization, showing a topographical difference in the N200 onset site. With regard to the N200 amplitude, a complex interaction (Group by Ear by Tone by Electrodes; $F(2, 368) = 3.44$, p $< .05$; X $= .75$) was significant. The analysis of this interaction showed that for the rare stimuli, in the premature group, N200 was significantly larger on central than on frontal ($F(1, 140) = 62.73; p < .001$) or than on parietal ($F(1, 140) = 82.92; p < .001$) electrodes. In control children, N200 amplitude was not different on frontal and central sites, but larger on both these latter leads than on parietal sites ($F(1, 44) = 8.37; p < .01$ and $F(1, 44) = 50.78; p < .001$, for the frontal- and the central-parietal comparisons, respectively). These interactions disappeared after normalization, demonstrating a difference in N200 amplitude but not in its fronto-central topography. By contrast, in the premature group, the N200 response was similar whatever tone or ear, with a central maximum. In other words, full-term controls, but not the premature children, showed a condition effect across both hemispheres, especially for the stimuli presented in the left ear.

DISCUSSION

The N100 revealed a clear contralateral organization of the auditory pathway with a faster and larger response over the temporal sites. This advantage for the left ear–right hemisphere pathway suggests a faster and more synchronized activation resulting in larger ERP wave. Tonnquist-Uhlén et al. (1995) also showed using pure tones that the N100 amplitude was larger for left than right ear stimulation. This left ear advantage may be related to the combined effects of early right hemispheric specialization and greater velocity of contralateral pathway from ear to cortex. The lack of difference between premature and full term children for this facilitation effect suggests that the underlying functional organization is established early in brain development. This is in agreement with the fact that the developmental N100 gain was smaller for the left ear than for the right ear (Tonnquist-Uhlén et al., 1995). At this first level of information processing, both groups appear to process as deviant only the low-pitched tones presented in the left ear.

Over the frontal sites, 100 ms later, information brain processing was clearly different between groups. The premature children only showed a central N200 response to all stimuli without further differentiation between them. By contrast, in full-term controls, rare stimuli appeared to elicit specifically a larger brain response starting over frontal leads. This would reflect the ability of full-term controls to combine spatial and tonal information to compute local rarity. In this auditory paradigm, although the subjects were not engaged in a demanding task, the present results support

our working hypothesis of an alteration of higher order information processing in premature children. However, we cannot exclude the role of other factors, such as group differences in the arousal level during the recording. Further analyses are thus needed to define whether all premature children showed such abnormalities, or if they are restricted to specific high risk subgroups.

ACKNOWLEDGMENTS

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Clumping Distractors around the Target Facilitates Performance on the Visual Search Task in the Elderly

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Fifteen elderly participants and 15 young controls were tested on a version of the visual search task to determine if stimulus location had an effect on reaction time (RT). Location was manipulated by presenting the distractors clumped around a target or spread apart on the screen. Elderly participants performed worse overall. Clumping proved to be an important manipulation in the target absent ($p < .001$), but not the target present, condition. The manipulation of array size (6 versus 12 distractors) proved significant regardless of probe presence ($p < .001$) or absence ($p < .001$). Since clumping the distractors significantly improved the search times in the elderly, this suggests that a deficit in attention contributes to an inefficient search strategy in the elderly. © 2002 Elsevier Science (USA)

INTRODUCTION

Focused attention is defined as the ability to attend to relevant stimuli while dismissing irrelevant stimuli. The visual search task (VST) is an experimental method used for assessing focused attention by requiring an individual to search for a target (a checkered circle) among an array of distractors (white-filled circles). In the simple feature search condition, when the target is present minimal attention is required, because the target is said to ''pop-out'' from the distractors (Treisman & Gelade, 1980). Reaction time for deciding whether or not the target is present or absent remains roughly equal regardless of probe status in the simple feature search condition.

In contrast, in the more complex conjoined condition, an individual must search for a target (a checkered circle) among an array of distractors (white-filled circles and checkered squares) that share at least one common feature with the target, but are independent of each other. The conjoined condition requires focused attention in order to select the relevant information about the target, extract pertinent features, and integrate them at a ''master map of locations.'' Furthermore, in the conjoined condition, when the target is present, the search will be self-terminating, but exhaustive, and ongoing when the target is absent (Treisman & Gelade, 1980).

Elderly individuals, assessed on a similar procedure to that described above, generally show slower RTs as compared to young individuals. With respect to the feature search task, these slowed RTs are independent of the array size. Alternatively, on the conjoined condition, increasing the size of the array causes the elderly to become substantially slower than the young in their attempts to detect the target (Plude & Doussard-Roosevelt, 1989; Foster et al., 1995). This suggests that although the elderly group is able to extract features (an ability necessary for performance on the feature search task), they are unable to integrate features together at the ''master map of locations'' (an ability necessary for adequate performance on the conjoined search task).

There are a number of factors that may contribute to the slowed performance in the elderly group (McDowd & Shaw, 2000). For example, they may have an impaired ability to locate a target in a large visual field (Plude & Hoyer, 1985). One type of search strategy that may be used to find the target among a large array size is analogous to an attentional spotlight that can be concentrated within a specific area of the display (Treisman & Gelade, 1980). As the elderly search through a display, this

concentrated spotlight moves around in order to detect the target amongst the distractors. If this attentional spotlight is damaged then it may increase the search time required to detect the target.

We thought it would be interesting to examine whether the performance of young and elderly subjects on a focused attention task could be altered by changing the location (clumped or spread) of the distractors around the target. We predicted that if focused attention acts like a spotlight engaged by the participant to search the visual field, then both young and elderly participants would be assisted in the detection of a target when the distractors were clumped in a 6×6 cm area than when they were spread throughout an 18×24 cm area. In addition, if the elderly do have impaired focused attention, constricting the search may be even more beneficial to this group.

METHODS

Participants

Fifteen young participants (age: 22 ± 4 years; education: 15.6 ± 2.7 years) and fifteen elderly participants (age: 72 ± 5 years; education: 13.1 ± 2.8 years) were tested on each of the VST conditions. Participants completed a number of neuropsychological tests to ensure that no one had any mild cognitive impairment. Participants were screened to ensure they were free from systemic illness, alcoholism, or dependence on sleeping aids and/or barbiturates.

Materials

The stimuli were 1 cm^2 (see next section for description) and created in Superpaint and were presented on a MacIntosh Powerbook 1400C laptop computer with a screen size of 20.23×27.09 cm.

Design and Procedure

The VST was composed of the feature condition and the conjoined condition. In both conditions, participants were asked to search for the target (checkered circle) in a stimulus array of either 6 or 12 items. The distractors in the feature condition consisted of white-filled circles. The distractors in the conjoined condition consisted of white-filled circles and checkered squares. The target was present on half of the trials (TP) and it was absent on the other half of the trials (TA).

The screen was divided into 12 separate quadrants. The target was placed in each of the quadrants, taking care to use all of the quadrants at least once for every possible combination of condition (feature, conjoined) and array size (6, 12). In the manipulation of location, stimuli were either confined to a single quadrant of the computer screen (clumped display), or spread throughout the 12 quadrants (spread display). Participants were administered a total of 192 trials consisting of an equal number of trials for location (clumped, spread), target presence (TP, TA), condition (feature, conjoined), and array size (6, 12).

Participants were told that each trial would be initiated by an asterisk on the screen. The asterisk remained on the screen for 500 ms. After the asterisk disappeared, the display of stimuli appeared and remained on the screen until participants decided whether the target was present or absent. Participants were told to look for the checkered circle, and they were instructed to press the key on the lower left corner of the keyboard when the target was absent and a corresponding key on the right side of the keyboard when it was present. The computer keys were marked with the words

"target present" or "target absent." Participants were informed to work as quickly and as accurately as possible. This was done to ensure there would be no trade-off between speed and accuracy. Reaction times (RT) were recorded in milliseconds.

RESULTS

The data for the target absent and target present conditions were analyzed separately. Two four-way ANOVA's were conducted across: condition (feature vs conjoined), location (clumped vs spread), distractor (6 vs 12), and age group (young vs elderly). Age group constituted a between subjects factor, while condition, location, and distractor were within subject factors.

Target Present

The four-way interaction was not significant however there were a number of significant three- and two-way interactions: location $\times$ condition $\times$ group ($F(1, 28) =$ 7.05, p < .05), condition $\times$ distractor $\times$ group ($F(1, 28) = 14.37, p < .05$), condition $\times$ distractor ($F(1, 28) = 31.99, p < .05$), distractor $\times$ group ($F(1, 28) = 8.04, p < .05$), condition $\times$ group ($F(1, 28) = 20.78, p < .05$), and location $\times$ distractor ($F(1, 28) = 5.61, p < .05$). Significant main effects ($p < .05$) were found for age group, condition, and distractor but not for location.

In general, performance was slower on the conjoined condition (822 ms) compared to the feature condition (644 ms), and the young outperformed the elderly (628 ms vs 840 ms). Despite the three-way interaction with location, we did not obtain significant two-way interactions for condition $\times$ location, or location $\times$ age. This suggests that clumping the stimuli did not facilitate the performance of the elderly on the conjoined and feature conditions when the target was present (see Fig. 1 for the average RT for the target present trials during the two conditions (feature vs conjoined), for the clumped and spread arrays, and for the young and elderly groups).
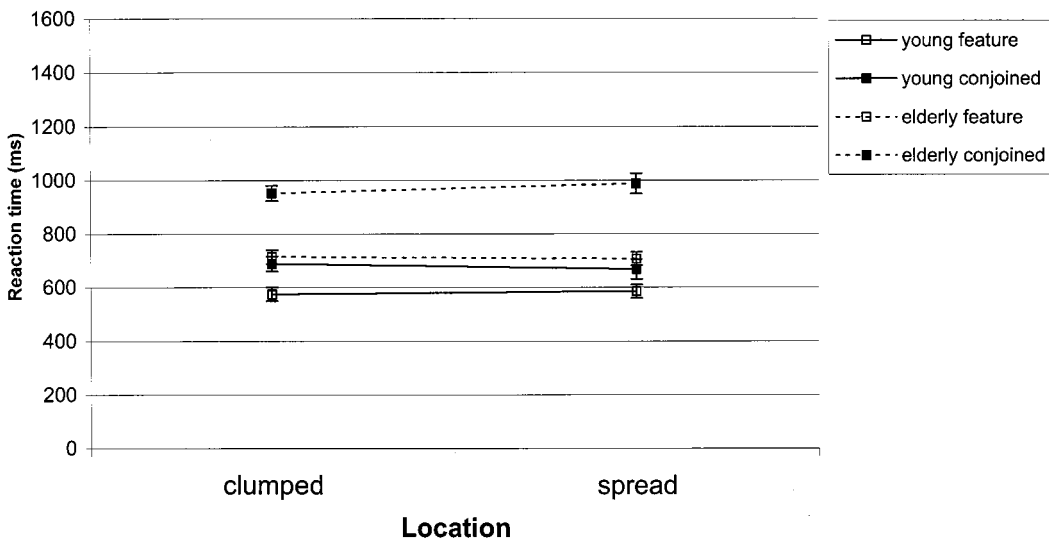

FIG. 1. Performance on target present trials in the young (solid line) and elderly (dotted line) for feature (open square) and conjoined (black square) conditions for manipulation of location (clumped and spread).

Target Absent

No significant four-way interactions were found. There were significant three-way interactions for location × distractor × condition ($F(1, 28) = 17.57$, $p < .05$), distractor × condition × group ($F(1, 28) = 11.4$, $p < .05$), condition × location × group ($F(1, 28) = 6.30$, $p < .05$), and location × distractor × group ($F(1, 28) = 4.06$, $p < .05$). There were also significant two-way interactions for location × group ($F(1, 28) = 15.41$, $p < .05$), distractor × group ($F(1, 28) = 4.33$, $p < .05$), condition × group ($F(1, 28) = 16.8$, $p < .05$), location × distractors ($F(1, 28) = 46.56$, $p < .05$), location × condition ($F(1, 28) = 13.65$, $p < .05$), and distractor × condition ($F(1, 28) = 86.42$, $p < .05$). Significant main effects ($p < .05$) were found for all of our factors in the target absent condition.

In general, performance was slower on the conjoined condition (1020 ms) compared to the feature condition (763 ms), and the young outperformed the elderly (720 vs 1064 ms).

Further examination of the interaction between location and condition revealed that when the distractors were clumped, the difference in means between the feature and the conjoined conditions was 2.5 times larger in the elderly group as compared to the young group (311 and 119 ms, respectively). When the distractors were spread apart, the difference in means between the feature and conjoined conditions was three times larger for the elderly group as compared to the young group (450 and 146 ms, respectively) (see Fig. 2 for the average RT for target absent trials in the two conditions (feature vs conjoined), for the clumped and spread displays, and for the young and elderly groups). This suggests that the elderly participants benefited from clumping the distractors, specifically during the conjoined condition.

By taking the difference of the means for the feature and conjoined spread conditions (averaged across array size), and subtracting this from the difference in means of feature and conjoined clumped conditions, we found that the elderly group had a fivefold decrease in RT in the clumped array compared to that of the young. Clumping improved performance by 139 ms in the elderly and 26 ms in the young controls.
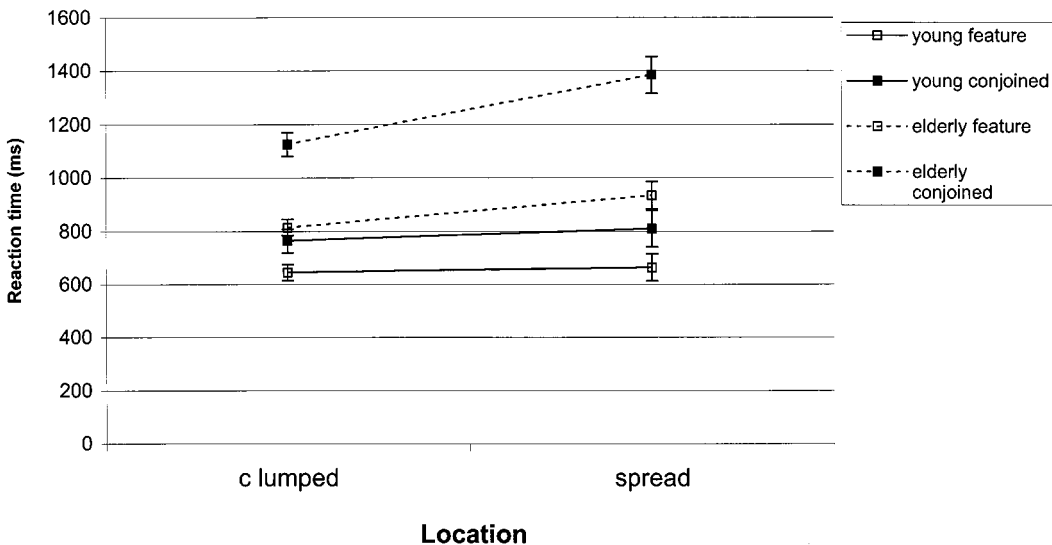

FIG. 2. Performance on target absent trials in the young (solid line) and elderly (dotted line) for feature (open square) and conjoined (black square) conditions for manipulation of location (clumped and spread).

Further examination of the location $\times$ distractor interaction indicated that the young were not significantly helped by clumping the distractors in the 6 distractor array, but they showed a significant improvement in performance in the 12 distractor array. In contrast, clumping the distractors improved the performance of the elderly, regardless of whether there were 6 or 12 distractors in the array size.

DISCUSSION

Our research supports the finding that there is an ageassociated impairment in focused attention. Further, we hypothesized that clumping distractors would decrease search times in the elderly population because grouping of the stimuli should constrict the spotlight of attention and perhaps aid their search strategy. Manipulating the location of the distractors did not play a significant role in search times for target present trials. Clumping distractors, however did decrease search times for the TA trials.

If clumping simply made visual search easier to perform across feature and conjoined conditions, then one would not have expected an interaction between condition and location as we obtained in the target absent analysis. Unlike the target present trials, where a search is terminated as soon as the target is located, having no target necessitates an exhaustive, ongoing search of the screen. It is possible that the elderly were using a different, inefficient search strategy to scan the display when the distractors were spread apart. Therefore, by narrowing the spotlight of attention, we may be improving search strategies in the elderly, thus negating differences in search strategies across age groups.

It was also shown that by clumping the distractors, the elderly, but not the young, benefited from the constricted location of the display when the array size was small (6 distractors). Interestingly, for both the young and elderly, narrowing the search field also ameliorated the increased search times that normally arise when there is a larger array of 12 distractors. Therefore, the young benefited from the clumping of the distractors when the array size was large, but the elderly benefited from the clumping of the distractors regardless of the array size. This provided evidence for the fact that when the window of attention was concentrated within a certain region, the elderly performed significantly better on the conjoined visual search task.

In the future, it will be interesting to explore how generalized cognitive slowing (McDowd & Shaw, 2000) may interact with visual search strategies on this modified visual search task.

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The Effect of Word Length on Hemispheric Word Recognition: Evidence from Unilateral and Bilateral-Redundant Presentations

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Visual half field studies have repeatedly demonstrated the left hemisphere's superiority for language processing. Previous studies examined the effect of word length on bilateral and unilateral performance by comparing foveal and parafoveal presentations. The present study removed the potential confound of acuity by using parafoveal presentations for both unilateral and bilateral trials. Twenty participants named 3-, 4-, 5-, and 6-letter words. The results supported previous findings, with right hemisphere performance being particularly degraded with increases in word length. There was no difference between left hemisphere and bihemispheric performance in terms of speed or accuracy, suggesting that bihemispheric performance is reliant upon the strategy of the hemisphere superior for language processing. Overall, the pattern of results supports the notion that the left hemisphere's superior linguistic capacity results from a more parallel processing strategy, while the right hemisphere is reliant upon a more sequential mechanism.   © 2002 Elsevier Science (USA)

INTRODUCTION

Investigations into cerebral lateralization of function have highlighted the superiority of the left hemisphere (LH) for language-based tasks. However, this LH superiority does not preclude the presence of right hemisphere (RH) linguistic capabilities. Research on split-brain and left hemispherectomy patients supports the presence of receptive language skills in the isolated RH, with the RH demonstrating good recognition of concrete/imageable words, but reduced ability in recognizing abstract words and virtually no capacity for phonological processing (Zaidel & Peters, 1981). However, interpretation of these findings is complicated by the fact that the intractable seizures suffered by participants prior to corpus callosotomy/hemispherectomy may have led to an atypical pattern of cerebral organization (Coslett & Saffran, 1998). Further, performance of the RH in isolation may not accurately reflect the contribution of the normal reader's RH to everyday language processing.

Investigation of RH language processing capacity in normal subjects can overcome difficulties associated with inferring function from clinical populations. Visual half field investigations of language processing typically demonstrate a robust right visual field (LH) advantage, thought to be an indication of the LH's superior linguistic capabilities (for review see Bradshaw & Nettleton, 1983). It has been suggested that this LH superiority for language processing may result from its predominantly holistic or parallel processing strategy, while the RH operates on letter strings via a more serial mechanism (Ellis, Young & Anderson, 1988; Bub & Lewine, 1988). To investigate this proposition, researchers have examined the effect of word length on reading performance. If word recognition depended on a sequential processing mechanism, one would expect slower response latencies and an increased number of errors in response to increases in word length. Such a finding has been repeatedly reported, with RH performance being particularly sensitive to increases in word length, (Young & Ellis, 1985; Ellis, Young, & Anderson, 1988).

While studies often assess processing strategy when only one hemisphere has immediate access to the stimulus, in everyday life it is more likely that both hemispheres will have access. Bilateral stimulus presentations can therefore be used to establish whether bihemispheric language processing reflects the strategy of the hemisphere superior for the task or a blending of processing styles. Bub and Lewine (1988) investigated the effect of word length on naming and lexical decision tasks, comparing left visual field, right visual field, and foveal presentations. Their results indicated that although foveal performance was faster and more accurate than either of the visual fields, the overall pattern found with foveal presentation most closely matched that of the right visual field (LH). They suggest that bihemispheric performance reflects the efficient LH processing strategy, while RH word recognition is mediated by a sequential analysis of individual letters. However, it is well known that retinal acuity decreases with increases in retinal eccentricity (Anstis, 1974). Hence by comparing unilateral and bilateral presentations, Bub and Lewine's study compared foveal and parafoveal vision. Given the high acuity in the fovea, it is not surprising that they found greater accuracy and faster response latencies for centrally fixated words.

The present study sought to compare unilateral and bilateral parafoveal performance in response to increases in word length. Marks and Hellige (1999) have demonstrated that, when using bilateral-redundant displays, the target stimulus is processed with the same efficiency and strategy as it would have been had there been only one copy of the stimulus. Thus redundant bilateral displays can be used rather than central foveal presentation to avoid confounding foveal acuity and retinal eccentricity. Performance when one hemisphere has immediate access to the stimulus can then be compared with performance when both hemispheres have simultaneous access, without making allowances for constraints on discriminability. By comparing bilateral and unilateral performance in this manner, we can draw inferences about the nature of hemispheric interaction for language processing.

If RH language processing is mediated by a predominantly sequential mechanism, RH performance should be particularly sensitive to increases in word length. Further, if Bub and Lewine (1988) are correct in suggesting that the LH dominates language processing for bilaterally presented words, there should be no difference in performance for stimuli presented to the right visual field and both visual fields simultaneously, as the difference in retinal eccentricity has been removed.

METHOD

Participants

Twenty (M = 5, F = 15) right-handed (Oldfield, 1971) students participated in the study as a course requirement. All subjects reported normal, or corrected to normal, visual acuity and were native speakers of English.

Stimuli

One hundred twenty words were selected from the MRC Psycholinguistic Database for use as the experimental stimuli, with 30 words in each of four word lengths: 3, 4, 5, and 6 letters. The sets of words were equated for frequency (Kucera & Francis, 1967) and imageability (Toglia & Battig,1978; Gilhooly & Logie, 1980). None of the word groups differed statistically in overall frequency or imageability.

The stimuli were displayed horizontally in white upper-case sans-serif font against

a black background and emitted a light of approximately 245 candelas/m^2 intensity. Each word subtended a vertical angle of 1.2° and a maximum horizontal angle of between 2.9° and 5.3° at a viewing distance of 500 mm. The central fixation cross subtended a visual angle of 1.2° vertically and horizontally. The middle of each word was centered at a point 5.3° to the left or right of the central fixation point. The inner edge of any word was never closer than 2.6° to central fixation.

Apparatus

The experiment was controlled with a 486 PC interfaced with an eight channel digital interface card, 15″ color monitor and an on board millisecond timer (Blue Chip Technology; DCM-16). The refresh time of the screen was approximately 17 ms. All stimulus presentations were timed to begin with the first vertical retrace of the screen (thus, the duration of each presentation was a multiple of the refresh time of the screen).

The experiment was conducted in a quiet, well-lit room, free from distractions. Participants were seated in front of a matt black display panel into which the computer monitor was positioned centrally. A chin rest was fixed 500 mm in front of the display to keep head position constant. Verbal response times were recorded via a microphone mounted immediately in front of the chin rest. The microphone was connected to a voice-activated switch. The experimenter recorded the accuracy of participants' responses using a two-button response. Eye movement was monitored using a video camera and zoom lens, mounted directly above the computer monitor and focussed on participants' eyes.

Design

Each participant completed 384 trials: 24 practice trials and 360 experimental trials. The 120 experimental stimuli (30 words from each word length 3–6 letters inclusive) each appeared once in the LVF, once in the RVF, and once in both visual fields (BVF) simultaneously, totaling 360 experimental trials. The order in which the words were selected from the list and the stimulus location (LVF, BVF, RVF) were randomized independently for each participant.

Procedure

Participants were tested individually in an experimental session lasting approximately 40 min. Before the experimental trials commenced, participants were given the 24 practice trials to familiarize them with the task. At the start of each trial, a central fixation cross was presented. Once 1496 ms had elapsed, the stimulus items were presented for 119 ms. Total stimulus presentation time was limited to 119 ms in order to minimize the effects of scanning eye movements (Pirrozzolo & Rayner, 1980). The central fixation cross remained lit until the experimenter scored the trial for accuracy. Once accuracy had been recorded, a new trial commenced in 1496 ms.

Participants were advised that words would appear to their left, right, or both fields of view, and that they were required to say the word as quickly and as accurately as they could. Trials in which a participant took longer than 1500 ms or less than 100 ms to generate a response were automatically rejected by the computer and replaced with an identical trial within the remainder of the block. After each response,

the experimenter scored the accuracy of the trial using a two-button panel. A trial was classified as incorrect if the participant reported the wrong word, was not able to say the word, or mispronounced the word.

RESULTS

Reaction Time

A measure of reaction time (RT) was generated by averaging the RTs for correctly identified trials. Univariate outliers were controlled by rejecting and replacing all trials with an RT in excess of 1500 ms.

A repeated measures analysis of variance (ANOVA), with visual field (LVF, BVF, and RVF) and word length (3, 4, 5, and 6 letters) as within subjects factors, reveals that RT increased as a function of word length [$F(3, 57) = 31.83, p < .001$]. RTs for trials presented to the LVF were, on average, 73 ms slower than those presented to either the RVF or BVF [$F(2, 38) = 31.43, p < .001$]. RTs for trials directed to the RVF and BVF did not differ [$F(1, 19) = 0.38$, ns].

Increases in word length had a greater effect on RTs for the LVF than either the BVF or RVF, resulting in a significant interaction between word length and visual field [$F(3, 57) = 3.52, p < .05$]. Word length affected naming latency in the LVF [$F(1, 19) = 3.45, p < .05$], but did not impact RVF [$F(1, 19) = 0.44$, ns] or BVF [$F(1, 19) = 0.91$, ns] performance. A post hoc analysis indicated no difference in the effect of length on performance between the BVF and RVF [$F(2, 38) = 1.57$, ns] (see Fig. 1).

Response Error

Response error was measured by averaging the number of errors committed in response to items in each of the 4 word lengths (30 items per word length). An ANOVA revealed that the number of errors increased as a function of the longer word lengths [$F(3, 57) = 15.03, p < .001$]. The side of stimulus presentation contributed significantly to the number of errors made [$F(2, 38) = 9.87, p < .01$], with the LVF exhibiting a higher number of errors relative to both the BVF [$F(1, 19) = 20.28, p < .0001$] and the RVF [$F(1, 19) = 12.16, p < .001$]. Again, performance for presentations directed to the RVF and BVF did not differ [$F(1, 19) = 0.97$, ns]. The interaction between visual field and word length approached significance [$F(3, 57) = 2.35, 0.05 < p < .01$], indicating a greater effect of word length on LVF performance (see Fig. 2).
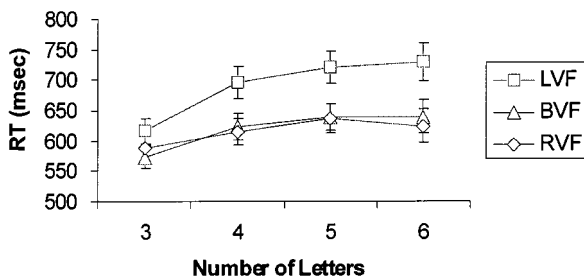

FIG. 1.   Mean response latency as a function of word length and visual field.
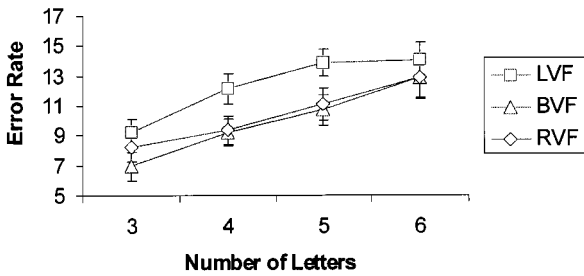
FIG. 2. Mean response error as a function of word length and visual field.

DISCUSSION

The present results support the notion of a sequential mechanism in language processing, with increases in stimulus length corresponding to increased response latencies and error rates across visual fields. The interaction between visual field and word length indicates the RH's particular sensitivity to increases in stimulus length, a finding that is consistent with previous research (Ellis, Young, & Anderson, 1988; Young & Ellis, 1985; Bub & Lewine, 1988). Our results suggest that word recognition in the RH is conducted via a sequential analysis of letters, reflected by an increase in response latencies as words become longer. LH response latencies were less affected by increases in stimulus length, consistent with the notion that the LH's relative efficiency reflects a more ''whole-word'' or parallel processing style (Bub & Lewine, 1988; Ellis, Young, & Anderson, 1988). Other indicators of sequential processing, such as point of irregularity (Coltheart & Rastle, 1994) and orthographic uniqueness point (Kwantes & Mewhort, 1999) could be tested in future to investigate further this LH/RH processing disparity.

The finding that RVF and BVF performance did not differ in terms of either speed or accuracy supports the proposition that when both hemispheres have immediate access to a stimulus, overall performance reflects that of the hemisphere superior for the task. Our data are in line with Bub and Lewine's (1988) finding that the pattern of performance for foveally presented words reflected that of words presented in the RVF. Although Bub and Lewine (1988) documented faster and more accurate performance with foveally presented words than those presented to the RVF, the superiority for centrally fixated words likely reflects a foveal acuity advantage. Because the present study utilized parafoveal presentations for both unilateral and bilateral trials, we avoided confounding retinal acuity with discriminability. The similarity between BVF and RVF performance patterns therefore offers further evidence to suggest that bihemispheric word recognition relies predominantly on LH processing mechanisms. The fact that RVF and BVF performance patterns were found to be statistically indistinguishable, with no evidence of a bilateral redundancy gain, argues against the notion of interhemispheric collaboration for this type of task. Instead, it appears that word recognition depends heavily on LH processing mechanisms, with little input from the RH. How the hemispheres coordinate and regulate this processing is yet to be determined.

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Is Surface Dysgraphia Tied to Semantic Impairment? Evidence from a Case of Semantic Dementia

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Recent models of lexical processing suggest that written spelling partly depends upon the semantic system. According to these models, a deterioration in word meanings would necessarily lead to a spelling impairment, especially for low-frequency and orthographically irregular words. We report a case study of a patient (MK) with semantic dementia who presents impairments in knowledge of word meanings and surface dysgraphia. By specifically identifying concepts that are still known or that are partially or completely deteriorated, we show that the patient's spelling deficit is highly correlated with word comprehension. These data confirm that surface dysgraphia is directly linked to the breakdown in semantic memory. © 2002 Elsevier Science (USA)

INTRODUCTION

Semantic dementia is a variant of frontotemporal dementia, characterized by a progressive deterioration of semantic memory, in the presence of relative preservation of episodic memory, visuospatial functions, executive functions, syntax, and phonol-

ogy. With respect to language, semantic dementia is responsible for word comprehension and naming deficits, whereas phonology and syntax are usually well preserved. Spelling impairment has also been reported in many cases of semantic dementia (e.g., Hodges, Garrard, & Patterson, 1998). These patients often demonstrate surface agraphia characteristics: they are better at spelling orthographically regular than irregular words, and tend to produce phonologically plausible spelling errors (e.g., *crapaud* 'toad' → CRAPOT). However, the relationship of this particular deficit with semantic memory impairment has received little consideration in the neuropsychological literature. By means of a group study, Graham, Patterson, and Hodges (2000) recently showed that surface dysgraphia is a predictable feature at the moderate stage of semantic dementia. Moreover, by resorting to the connectionist model of Seidenberg and McClelland (1989), these authors proposed that deterioration in word meanings would lead to the production of phonological plausible errors, since the semantic system plays a central role in the computation of orthography from phonology. In functional architecture models of spelling (e.g., Goodman & Caramazza, 1986), on the other hand, a semantic deficit would not necessarily entail difficulties in word spelling since: (1) the production of written words to dictation may be achieved through a lexical nonsemantic route, which maps phonological input representations to orthographic output representations without engaging the semantic system, and (2) the importance of the integrity of the semantic system for the preservation of spelling abilities is not specified. In this study, we report a patient suffering from semantic dementia (MK) whose performance in written spelling to dictation supports the dependence of lexical agraphia on semantic memory deficit.

CASE REPORT

At the time of testing, MK was a 71-year-old, right-handed female. She is a native speaker of French, has a grade 13 education and worked as an executive secretary. The analysis of premorbid samples of handwriting confirmed that she was good at spelling. In November 1999, she was referred to the memory clinic at the Institut universitaire de gériatrie, Sherbrooke, because of word-finding problems. At that time, MK felt these problems had begun up to 3 years previously, with progressive worsening. A CT-scan (May 2000) revealed a focal atrophy of the temporal region, more marked on the left side.

Neuropsychological and Language Evaluation

MK showed no clinical signs of apraxia, agnosia, acalculia, or attentional deficits. Except for semantic memory, her memory abilities were within the normal range. Spontaneous speech was fluent, well articulated, and grammatically correct but presented many signs of word finding difficulties: miscarried sentences, latencies, and occasional semantic paraphasias. Repetition was flawless for both words and nonwords. Reading was slightly impaired and marked by the presence of occasional regularization errors. Written spelling of nonwords was well preserved (5/5) but the patient's performance on word writing to dictation was canonical of surface dysgraphia with production of numerous phonological plausible errors and performance affected by orthographic regularity (regular = 18/18; irregular = 10/18) and lexical frequency. Sentence comprehension was unimpaired.

Semantic Evaluation

MK showed important difficulties on various tasks exploring verbal and nonverbal semantic processing: picture naming, semantic feature questionnaire, synonymy

TABLE 1
MK's Results and Control Subjects' Performance (Mean and
Standard Deviations) on Semantic Tasks

Semantic tasks	MK	Controls	(SD)
Picture naming (76)	46	70.3	(3.2)
Semantic feature questionnaire			
living categories (64)	42	56.3	(6)
nonliving categories (64)	57	62.1	(2.5)
Synonymy judgement tasks			
living categories (40)	24	35	(3)
nonliving categories (40)	34	39	(1)
Word categorization			
living categories (120)	104	115.5	(5)
nonliving categories (120)	110	114	(2)
Definition/written word matching			
perceptual features (40)	29	38	(2.3)
nonperceptual features (40)	40	40	(0)
Pyramids and Palm Trees Test			
pictures (50)	45	49	(1.3)

judgement tasks on triplets, picture to picture matching condition of the Pyramids and Palm Trees Test, etc. A summary of MK's results on semantic tasks is presented in Table 1.

Summary and Diagnosis

MK presented with an important semantic deficit whereas other cognitive functions that do not depend on semantics were largely preserved. This deficit was not tied to the nature of the input code and resulted in important word comprehension problems. MK also showed spelling difficulties, characterized by clinical features of surface dysgraphia. This clinical profile, associated with the focal degeneration of temporal lobes, suggested a diagnosis of semantic dementia (Hodges et al., 1992).

EXPERIMENTAL STUDY

The main purpose of this study was to investigate the possible relationship of MK's spelling deficit with semantic memory impairment.

METHOD

Comprehension Tasks

MK underwent two comprehension tasks devised to identify known and unknown concepts. The semantic battery comprised 216 stimuli pertaining to living (97) and nonliving (119) semantic categories, controlled for orthographic complexity and lexical frequency. Words were categorized as regular (105 stimuli) or irregular (111 stimuli) following criteria established for writing to dictation by Beauvois and Derouesné (1981). The mean frequency for living and nonliving categories was matched.

a. Semantic questionnaire. The patient was presented with a spoken semantic questionnaire, directly drawn from the Chertkow, Bub, and Caplan (1992) study and probing the following semantic properties: general superordinate (e.g., is a sheep an animal, an object, or a plant?), same category superordinate (e.g., is a sheep a fish,

an insect, or a mammal?), subordinate perceptual feature (e.g., does a sheep have a long or a short tail?), subordinate nonperceptual feature (e.g., is a sheep domestic or not?). MK's performance was scored as follows: a score of 3 was given when the performance was flawless; a score of 2 was given when the patient could answer both questions related to superordinate information but could not answer any subordinate questions; a score of 1 was given when the patient could only answer the general superordinate question; a score of 0 was attributed when the patient said she did not know the word stimuli and could not answer any questions.

b. Picture/Name agreement judgement task. A stimuli list of 216 line drawings corresponding to the word stimuli used in the semantic questionnaire was used. Each picture was presented in separate sessions for the picture/spoken name agreement judgement task, once with the corresponding word (e.g., is this a sheep?), once with a close semantic foil (e.g., is this a pig?), and once with a distant semantic foil (e.g., is this a rhinoceros?). Scores of 3, 2, 1, and 0 were attributed to MK's performance when she responded accurately to 3, 2, 1, or none of the trials in which the picture was presented.

Written spelling to dictation task. MK was asked to write to dictation the 216 word stimuli used in the comprehension tasks, presented in a random order.

MK's performance on the semantic questionnaire and the written spelling to dictation tasks was compared to the results of three female controls matched for age and educational level (mean age = 72.7 years, mean education = 12 years).

RESULTS

Treatment of Data

A concept was considered as well known when scores of 3 were recorded on both comprehension tasks; a concept was considered as partially known when scores of 2 were recorded on both comprehension tasks or when a score of 3 was recorded on one comprehension task and a score of 2 on the other task; a concept was considered as unknown when scores of 1 or 0 were recorded on one task along with scores of 0, 1 or 2 on the other task.

Comprehension Tasks

MK's performance on comprehension tasks was tied to semantic categories. As for the background testing, she was better for nonliving (known = 80/119, 67%; partially known = 36/119, 30%; unknown = 3/119, 3%) than for living categories (known = 51/197, 53%; partially known = 33/97, 34%; unknown = 13/97, 13%) and the difference was mainly due to the performance on animals (known = 10/39, 26%; partially known = 23/39, 59%; unknown = 6/39, 15%). The difference between living and nonliving categories in comprehension tasks was significant (χ^2 = 4.21, d.f. = 1, $p < .05$). The patient's performance was also tied to lexical frequency (known concepts: low-frequency words = 58/107, 54% correct; mid-frequency words = 37/62, 60% correct; high-frequency words = 36/47, 77% correct), but the difference did not reach significance. The mean score for the controls on the semantic questionnaire only was: known = 211/216, 98%; SD = 4; range = 205–215/partially known = 3/216, 1.4%/unknown = 2/216, 0.9%).

Written Spelling to Dictation Task

MK presented with an important impairment in spelling to dictation (155/216, 72% correct—mean score for the controls was 209.7/216, 97% correct, SD = 3.1;

TABLE 2
Number and Percentage Correct in Written Spelling to Dictation of Regular and Irregular Words According to the Performance in Comprehension Tasks

	Regular	Irregular	Total
Known words	66/70 (94%)	45/61 (74%)	111/131 (85%)
Partially known words	30/33 (91%)	11/36 (31%)	41/69 (59%)
Unknown words	1/2 (50%)	2/14 (14%)	3/16 (19%)

range = 205–214) and her performance was largely influenced by orthographic complexity. She scored 97/105 (92% correct—mean score for the controls was 104/105, 99% correct, SD = 1.7; range = 102–105) on regular words and 58/111 (52% correct—mean score for the controls was 105.7/111, 95% correct, SD = 2.2; range = 103–109) on irregular words and the difference was highly significant (χ^2 (1) = 40.9, p < .001). Lexical frequency also appeared to play an important role (Kendall's correlation coefficient = 1, p < .001) on her performance (low-frequency words = 66/107, 62% correct; mid-frequency words = 47/62, 76% correct; high-frequency words = 42/47, 89% correct). Except for 2 nonphonological plausible errors and 2 mixed errors, the patient mainly produced phonological plausible errors (57), consisting in orthographic regularizations (e.g., ''crapaud'' (toad) → CRAPOT).

As shown in Table 2, MK's performance in written spelling to dictation also appeared to be closely tied to her performance in comprehension tasks (Kendall's correlation coefficient = 1, p < .001). Her ability to correctly spell the known concepts was good (85% correct), whereas she encountered much more difficulty when requested to spell words for which her comprehension was incomplete (59% correct) or very poor (19% correct), and the difference was even more marked when the analysis was restricted to irregular words only (known concepts = 74% correct; partially known concepts = 31% correct; unknown concepts = 14% correct).

DISCUSSION

We have reported the case of a patient with semantic dementia who exhibits the prevalent feature of surface dysgraphia. She was better at spelling orthographically regular than irregular words, and produced almost exclusively phonological plausible errors. A close relationship of this spelling deficit with semantic impairment was also demonstrated. By specifically identifying concepts that are still known or that are partially or completely deteriorated, we showed that MK's spelling deficit was highly correlated with word comprehension. The three-routes model of written production, in which access to orthographic output representations can be achieved without engaging the semantic system, cannot easily account for this pattern of performance. Like Graham and colleagues (2000), we suggest that surface dysgraphia is directly linked to the breakdown in semantic memory and that this association of deficits could easily be explained within the theoretical model of lexical processing proposed by Seidenberg and McClelland (1989).

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Effects of Object Asymmetry on Visual Attention

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Unilateral neglect has been demonstrated relative to the intrinsic left side of objects, even when presented in the preserved hemispace. These results have been interpreted as evidence of an object-centered reference frame. In the present study, neurologically normal individuals were presented with letter stimuli having distinguishing features to the right (R) or left (J) of their intrinsic midline, shown in normal and mirror parity, and in six angle rotations. RTs confirmed that participants rotated the letters to the upright to decide parity: such rotation would align the object-centered and viewer-centered frames of reference, suggesting that not controlling for mental rotation would confound this effect. In addition, a dot, presented lateral to the main letter stimulus, resulted in quicker parity decisions when on the maximally-informative side of the letter. Together, the results suggest that apparent object-centered neglect may arise from the combined effects of mental rotation and within-object information asymmetries.   © 2002 Elsevier Science (USA)

INTRODUCTION

The attention of unilateral neglect (UN) patients is biased toward the right side of space. The two central views of this attentional bias are Posner's (1984) theory that parietal-lobe lesions result in difficulties disengaging attention from the ipsilesional side of space, and Kinsbourne's (1987) model, which suggests that the focus of attention is determined by competition between hemispheric systems so that unilateral brain damage leaves the demands of one hemisphere unchecked. Attention is, however, directed in the service of achieving an adequate representation of the world. Thus, we must ask, what representations underlie the demands for attention, and ask particularly about the possibility of multiple reference frames.

Studies with UN participants have been interpreted as showing that visual attention is allocated according to distinct frames of reference: the neglected ''side'' may refer to left of the environment, left of the subject's own body/head, or left of an object-centered coordinate frame (Driver & Halligan, 1991), or, in one case, the right-most letters of written words (Caramazza & Hillis, 1990). Experiments using asymmetrical figures have shown that the left side of an object may be neglected even when presented in the right side of space (Driver & Halligan, 1991). While such data have

been interpreted as evidence for a distinct object frame of reference, this interpretation has been questioned (Buxbaum et al., 1996; Drain & Reuter-Lorenz, 1997). To further explore the mechanisms for allocating visual attention, the experiment in the present study aimed to replicate and extend a previous study by Maguire, Corballis, and Bates (submitted) that used asymmetrical letters to produce an object-centered frame of reference.

Experimental evidence for separate viewer- and environment-centered frames of reference was first demonstrated by Calvanio et al. (1987) and Ládavas (1987). For example, Ládavas (1987) had viewers tilt their heads (left or right) relative to a display. By thus disentangling the left of the viewer-centered from the left of the environment-centered reference frames, she was able to demonstrate the existence of neglect in both viewer and environment representations. Subsequently, Farah et al. (1990) also reported evidence that attention could be affected by both viewer- and environment-centered frames of reference but not by an object-centered frame of reference.

In contrast to Farah et al.'s (1990) findings, Driver and Halligan (1991) demonstrated a significant object-centered neglect relative to the figure's mid-line or principal axis. Same/different judgments were recorded to asymmetrical, elongated, nonsense shapes presented upright or tilted 45° clockwise or anticlockwise, so as to uncouple the viewer- and object-centered reference frames. Their case-study participant (PP) neglected differences on the left side of the figures, not only when they were presented upright (left in the left side of space), but also when the object was tilted clockwise so that the left side of the figure fell entirely on the right side of the viewer's frame of reference. These results were interpreted as clear evidence of object-centered neglect.

This finding that object-centered neglect can be demonstrated in paradigms which require participants to discriminate between the object's left and right gained further support from Behrmann and Moscovitch (1994). By using stimuli with an intrinsic left and right half (asymmetrical capital letters such as B and R), these authors reported both a replication of Farah's lack of evidence for an object-centered frame of reference in objects with no intrinsic left-right (for instance side views of animals), and a replication of Driver and Halligan's (1991) evidence for object-centered neglect. A number of studies followed these seminal findings, using the method of rotating objects in and out of left and right visual fields. Some studied neurologically-normal (NN) participants (Umilta et al., 1995), and others UN participants (Maguire & Corballis, 1995; Tipper & Behrmann, 1996). All concluded that there was evidence that visual attention operated within object-centered as well as viewer- and environment-centered frames of reference. Moreover, Hillis and Rapp (1998) reanalyzed the raw data for individual participants in the Farah et al. (1990) study, and showed that while the group-analysis did not support a separate object-centered frame of reference, data from individual UN participants demonstrated that such a frame was dissociable.

However, there are at least two other interpretations for these results. The first is proposed by Buxbaum et al. (1996), who found that object-centered neglect appeared only when their participants were instructed to mentally rotate the image to the upright. In so doing, the left and right sides of the object were brought into alignment with the viewer's (and environment) left and right side. Mental rotation thus realigns the left of the object with the left of the viewer-centered representation, and does away with the need to explain these results in terms of an object-centered frame of reference. Most attempts to disentangle an object-centered reference frame may be thwarted by participant's realigning the object- and viewer-centered reference frames not only in translation within a 2D plane but also in parity.

In addition to these effects of mental rotation, Drain and Reuter-Lorenz (1997)

reported that NN participants selectively attend to the right side of asymmetrical letters in a letter-identification task. They suggest that distinguishing features may determine the direction of attention in both UN and NN participants. They did not, however, use stimuli for which the disambiguating feature was located on the left.

The aim of the present study was to extend the findings of Drain and Reuter-Lorenz (1997) by examining the allocation of attention to the left and right sides of asymmetrical objects in NN individuals. Two asymmetrical capital letters (R and J) were specifically chosen because the letter R has distinguishing information to the right of the midline, and the letter J has distinguishing information to the left of the midline. NN participants were not expected to demonstrate a difference in accuracy for reporting a dot on the left or right side of these letters, but attention directed to the informative side of the letter (i.e., right of the ''R'' and left of the ''J'') was expected to result in faster reaction times (RT). In order to explicitly examine the Buxbaum et al. (1996) hypothesis, a parity judgment task known to demand mental rotation was used.

METHOD

Participants

Fifteen NN participants (8 female), aged 35 to 63 years (mean age = 47) met selection criteria of no history of neurological injury, and being right-handed according to the Edinburgh Handedness Inventory (Oldfield, 1970) (mean EHI scores of 83 where +100 indicates exclusive right-handedness). Participants received $10.00 and a Certificate of Appreciation for their participation.

Experiment Stimuli and Equipment

The stimuli were asymmetrical uppercase letters (visual angle 1.5° × 1°). An ''R'' (distinguishing information to the right of the object) or a ''J'' (distinguishing information to the left of the object) were presented in white font on a black background, either with or without a small dot 1 mm from the maximum curve of each letter.

Each trial began with a 200 ms central fixation stimulus (+), subtending 2° of visual angle, subsequently replaced with the letter ''R'' or ''J,'' presented in normal or mirror parity with equal probability. Letters were presented in each of six different angles of orientation, ranging from 0 to 315°, in 45° steps clockwise from the upright (excluding 90 and 270° rotations increased the number of presentations in the other orientations without unnecessarily fatiguing the participants). Stimuli appeared with no accompanying ''dot'' on 50% of trials, and a dot on the left or right with equal probability on the remaining 50% of trials. The 96 stimuli were presented in five blocks of 192 trials each, totaling 960 trials for each participant.

Participants were tested in a sound-attenuating, distraction-free room, and were seated at a distance of 57 cm from the display. Viewing was stabilized by a chin rest and a standard keyboard was used for the response keys, marked clearly by color and letters (e.g., an orange dot with an N′ for normal parity was placed over the ''O'' key on the keyboard).

Procedure

The participants were given verbal instructions describing the task. They made two key-press responses on each trial. The first decision was to judge whether the letter presented was of a normal or backward parity (e.g., normal or backward); and

the second was to judge whether a dot had been presented alongside the letter (e.g., dot or no dot). The participants were informed that both accuracy and speed were important in this experiment.

The experiment began with a set of 20 practice trials, as it was important to establish the participant's ability to make parity discriminations in the six different angles of orientation. They then completed the experimental trials. Between each of the five blocks, the participant paused for a 5 to 10 min rest. The session lasted for 75 to 90 min, depending on the time taken for rests. On completion of the final trial, participants were invited to comment on the experiment and to ask any questions.

RESULTS

All but one participant achieved high accuracy rates (average 97% for parity, and 99% for dot detection). The data for one participant's parity responses were removed from further analyses since their accuracy rate of 87% was below the criterion level of 94%. As there were no significant effects of gender on decision times for dot ($F(1, 12) = .06$, NS) or parity ($F(1, 12) = .4$, NS), RTs and this factor was collapsed in further analyses.

Repeated measures ANOVA analyses were conducted separately on the RT for decisions of parity and dot presence. None of the factors manipulated in this experiment had any significant effect on dot detection responses: side of dot, ($F(1, 13) = .45$, NS); rotation of stimulus, ($F(5, 65) = .2$, NS); stimulus parity, ($F(1, 13) = 3.2$, NS); or letter type, ($F(1, 13) = .97$, NS). By contrast, parity judgments (Greenhouse–Geisser adjustment applied), were significantly affected by: angle of rotation, ($F(2.10, 27.33) = 39.28$, $p < .001$); parity, ($F(1, 13) = 7.33$, $p = .02$; and letter-type, ($F(1, 13) = 6.32$, $p = .03$), but not side of presentation of the dot when present, ($F(1, 13) = .2$, NS). In addition, parity-judgments showed a three-way interaction, *parity × letter × dot* ($F(1, 13) = 6.87$, $p = .02$) that indicates more rapid RTs when the dot was on the informative side of the letter. Normal "J" stimuli with a left dot were more quickly reported than was the same letter with a right dot, while RT to a backward "J" with a left dot was longer than a backward "J" with a right dot.

To further investigate the effect of distinguishing information on RT, the letter and dot conditions were reorganized to form a two-level factor: (1) the "distinguishing-information" level, contrasting stimuli in which the letter's curve and the dot were co-lateralized, and (2) the "nondistinguishing information" level, where the dot was sited on the straight or "nondistinguishing" side of the stimulus. Mean RTs for the rotation, parity, and distinguishing-information condition showed a significant effect for the side with information, ($F(1, 13) = 6.87$, $p = .02$), where the mean RTs were significantly slower (1853 ms) when the dot was on the straight side of the letter than when it appeared on the informative or curved side of the letter (1774 ms) (see Fig. 2).

DISCUSSION

Consistent with the finding that mental rotation is an obligate stage in parity judgments (Corballis, 1982), RTs in the present study were proportional to the degree of rotation of the stimuli (see Fig. 1). In addition, the basic mental rotation effects noted by Cooper and Shepard (1973) were replicated, that is, the "R" stimuli were more rapidly rotated than were the 'J' stimuli,[1] and normal parities were quicker to decide

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[1] The capital letter "J" is the only left-facing capital letter in the modern alphabet. It is the most recent letter to be added to the alphabet and its shape was not certain until the early nineteenth century (Crystal, 1997).
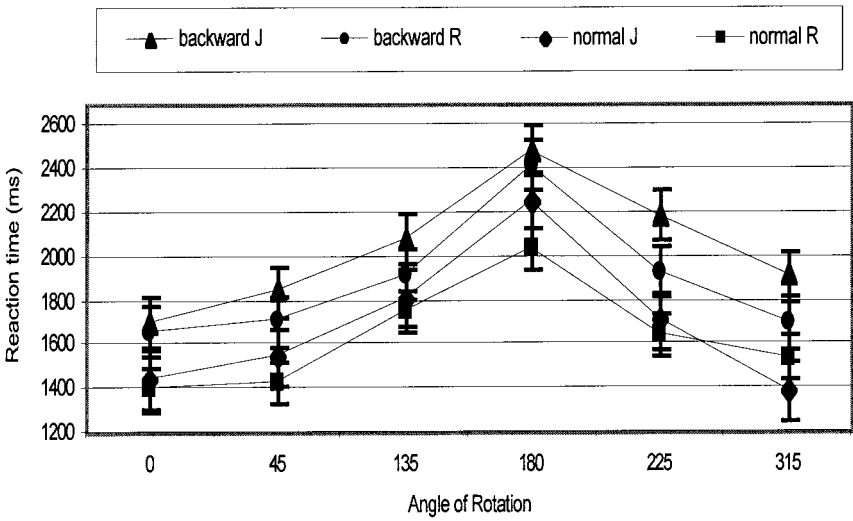
FIG. 1. Mean reaction times (and standard errors) for parity decisions as a function of angle of rotation (0, 45, 135, 180, 225, and 315), parity (normal or backward), and letter (''R'' or ''J'').

than backward parities. These results support Buxbaum et al.'s (1996) contention that UN participants may mentally rotate asymmetrical figures to the upright when making decisions involving the left and right of a figure. Whereas Buxbaum et al. (1996) assumed that their UN participants mentally rotated figures on request, the present study provides evidence of a mental rotation curve in the RTs. Future studies should control for mental rotation by examining the RT data for evidence of mental rotation.

The main aim of the present study was to ascertain whether NN individuals respond more rapidly to the informative side of a letter. This hypothesis was supported in that when a dot was presented to the side of the letter with distinguishing information, parity decisions were significantly speeded. This result supports Drain and Reuter-
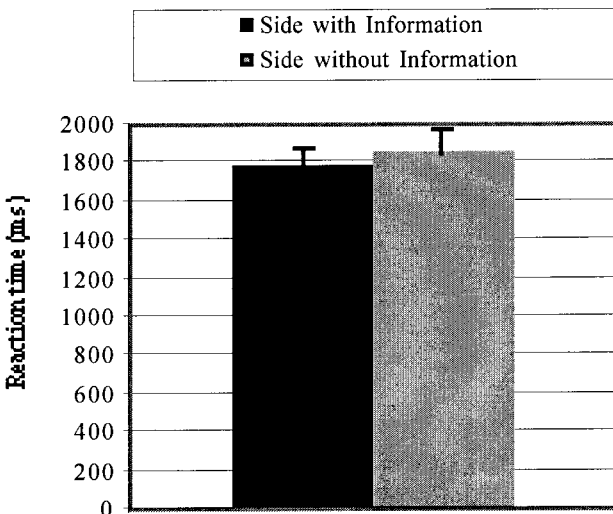

FIG. 2. Reaction times (and standard errors) for the informative and noninformative side of the letters ''R'' and ''J.''

Lorenz's (1997) finding that attention is selectively directed to the informative side of a letter, which in their study was the right side of right-facing letters, and in the present study included both the right side of right-facing letters and the left side of left-facing asymmetrical stimulus, such as the letter ''J.''

Together, these results with NN individuals suggest that attentional bias and mental rotation effects may be a more parsimonious and more general explanation of within-object neglect than are explanations that require a separate object-centered reference frame.

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Languages in Space

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The activation-orienting hypothesis and possible effects of hemispace for verbal stimuli in the native (Croatian) and foreign (English) language were studied on a sample of 72 healthy female right-handers. In an experimental design involving two competing commands referring to objects in left and right hemispace presented simultaneously to the two ears it was recorded which of the two was attended to first. The activation-orienting hypothesis was confirmed for Croatian but not for English. Clear dissociation between the two languages was found with respect to preferred hemispace: for the stimuli in the native language the subjects preferred the left hemispace, whereas for the stimuli in the foreign language they preferred the right hemispace. © 2002 Elsevier Science (USA)

INTRODUCTION

Beginning with the first studies of brain-damaged patients, particularly those suffering from aphasia, it has been clear that there is a strong relationship between motor and language activity. It has been found consistently by EEG and cerebral blood flow measurements that a task that depends more on one cerebral hemisphere than on the other, asymmetrically activates the specialized hemisphere, producing a contralateral attentional bias. This phenomenon is referred to as the activation-orienting hypothesis (Reuter-Lorenz & Kinsbourne, 1990). There has also been ample evidence of the relationship between spatial functioning, including, but not limited to the awareness of one's body, peripersonal and extrapersonal space on the one hand, and language on the other (Coslett, 2000).

Normal right-handed subjects typically misbisect line stimuli to the left of the actual center (leftward error) (McCourt et al., 2000). This is presumably a consequence of the differences between the two cerebral hemispheres in the allocation of attention, the right hemisphere being presumed dominant in allocation of attention, resulting in excess attention devoted to the contralateral, i.e., left, hemispace. Adding another stimulus may modify this difference in either direction—additional activation of the right hemisphere will increase the leftward error, whereas activation of the left hemisphere will reduce it, which is in accordance with the activation-orienting hypothesis. Behavioral, imaging, and other studies have supported the hypothesis that the right cerebral hemisphere is capable of directing attention both toward the contralateral (left) and the ipsilateral (right) hemispace, as opposed to the left cerebral hemisphere that directs attention only to the contralateral (right) hemispace (Weintraub & Mesulam, 1987; Loring et al., 1994). It has also been found that context, the nature of the task, or task-specific demands influence the allocation of attention and may affect the response times and accuracy. The left cerebral hemisphere has been shown to be specialized for verbal, spanning, sequential, linear, or narrow attentional processes, whereas the right cerebral hemisphere seems to be specialized for visuospatial, scanning, holistic, gestalt, or broad types of attention (Loring et al., 1994; Fotiades et al., 1998).

The aim of this study was to examine possible effects of the active hand on the ear preference in processing verbal stimuli in the native (Croatian) and foreign (English) language. Based on the activation-orienting hypothesis, the forced use of one hand should activate the contralateral hemisphere, orienting in turn auditory attention to the ear contralateral to that hemisphere, i.e., ipsilateral to the active hand. In an experi-

mental design involving two competing commands presented simultaneously to the two ears this should be manifested as preferential reaction to the command presented to the ear ipsilateral to the active hand. In terms of ear advantage in processing verbal stimuli in the native language it was reasonable to expect greater right-ear advantage with the active right hand than with the active left hand, but due to the robustness of the REA no switch to the left ear advantage was expected with the use of the left hand. With respect to the hemispace bias it was expected that the subjects would exhibit a rightward bias, i.e., greater attention to the right hemispace. For the stimuli in the foreign language less pronounced effects of any factor were expected due to the presumably more diffuse cerebral representation of the foreign language.

METHOD

The test objects were: *bottle* (a small brown 200-ml bottle), *paper* (a crumpled piece of A4 paper), *chicken* (a 6 cm high toy chicken), *letter* (a regular size stamped and addressed envelope), *picture* (a 10 × 13 cm photo of a landscape), and *water* (a 200-ml clear plastic cup half-filled with water). They could all be easily manipulated with one hand. The objects were placed on the table in a semicircle in front of the subject. The distance between each object and the subject's hand in resting position—in midline with respect to the body—was identical (25 cm), and the distances between the objects were the same (16 cm). The first three objects were positioned to the left of the midline (left hemispace), whereas *letter, picture,* and *water* were to the right (right hemispace). As in English, the Croatian terms for the six objects are two-syllable words with stress on the first syllable.

The commands were of the form *Take the . . .* , recorded in English and Croatian by a bilingual female speaker. The Croatian equivalent of the imperative form of the verb *take* is a two-syllable form *uzmi,* and since Croatian does not have articles the stress pattern and the duration of *take the* correspond to *uzmi.* Each command actually consisted of two parts: (1) the verb (in English verb + article), and (2) the object to be picked up. The verbal part and the words denoting the objects were recorded once in each language, stored digitally in the computer, and rerecorded onto the test disk in all possible combinations. The two competing commands presented to the left and the right ear were synchronized both with respect to the beginning of the utterance and with respect to the onset of the word denoting the object. In this way any bias caused by possible differences in duration or onset was avoided. What the subjects would hear during the test, for example, were pairs like *Take the letter* (left ear)–*Take the bottle* (right ear). Since the verbal part was in fact the identical token presented to the two ears symultaneously the difference between the ears occurred only in the second part where the two commands actually differed in the object to be picked up. Another advantage of this ''double'' synchronization is the effect of forcing the subject's auditory attention back to the midline before each new pair of objects. The interstimulus interval was 4 s.

The subjects were 72 female university students (mean age 19.8 years), whose native language is Croatian and who had learned English as a foreign language in elementary and secondary school (on the average 8 to 10 years—late learners, starting at the age of 10) and had scored 75% or better on a test of English administered two weeks prior to testing. Based on the 12-item handedness and 7-item footedness questionnaire they were classified as right-handed and right-footed and had reported no neurological or hearing abnormalities. The symmetry of their hearing was checked by the acumetric Weber test. Depending on which hand was to be used to manipulate the objects, the subjects were assigned to the right-active or left-active group (36 subjects in each group).

The task was to listen to the commands presented through the stereophonic headphones, pick up and set down the two objects referred to in the commands in any order they wanted, and return the active hand to the resting (midline) position on the table. The nonactive hand was to be kept in the lap.

Testing was done individually in a quiet room. The subject was seated at the table, *vis-à-vis* the experimenter who recorded the order of her picking up the objects. After oral instructions, each subject was given a trial run consisting of monoaurally and binaurally presented commands in each language. The test itself consisted of 12 pairs of commands alternating in blocks of three for each language—three English pairs, three Croatian, etc. The two test languages were never mixed within a pair. After the first 12 pairs the headphones were reversed and the procedure repeated. This yielded a total of 24 pairs—12 in each language—per subject. One half of the command pairs referred to objects from the same hemispace (left or right) and the other half to the objects from both the left and the right hemispaces. The commands were presented through the stereophonic headphones, at the comfortable listening level (70 dB).

Where appropriate, laterality index (LI) was calculated as LI = (R − L/R + L) × 100, where R refers to the right ear or right hemispace and L refers to the left ear or left hemispace. Positive values indicate right ear advantage (REA) or preferential grasping into the right hemispace. Negative values indicate left ear advantage (LEA) or preferential grasping into the left hemispace. Statistical analysis was done with Statgraphics software on raw data and on laterality indices.

RESULTS AND DISCUSSION

It should be stressed that in all conditions there is some control of the less active hemisphere. Namely, the maximum range of laterality indices is from −100 for the extreme condition of a perfect left-ear-advantage to +100 for the opposite extreme of a perfect right-ear-advantage, with zero value indicating no ear advantage, i.e., symmetrical activation of cerebral hemispheres. For all responses, one-way analysis of variance with hand (left, right) as independent variable and the laterality indices as the dependent variable has shown the significant main effect of hand for the stimuli in the native language (Croatian) ($F = 6.211$; $p = .02$), but not in the foreign language (English) ($F = 1.642$; $p > .05$). In all conditions, however, there was still the right-ear advantage (REA) represented by positive values (Table 1a).

In order to tease apart the effects of the active hand from the possible effects of the objects' positions in the space, i.e., left or right hemispace, separate analyses were carried out on the responses to commands that involved both objects from the same hemispace, and on the responses that involved objects positioned in different hemispaces. There were 12 responses per subject for each of the two conditions.

In the 12 pairs in which both objects were positioned in the same hemispace (left or right) the subjects had, in fact, only one decision to make—which ear to attend to first. In other words, the question was which of the two objects referred to in the competing commands presented symultaneously to the two ears will be picked up first. Two-way analysis of variance on raw data with hand (left, right) and language (Croatian, English) as independent variables has shown the main effect of hand ($F = 7.628$; $p = .01$), and marginally of language ($F = 3.416$; $p = .06$). Laterality indices have shown a REA across conditions and languages. Within-language analysis of laterality indices for Croatian stimuli has shown a significantly ($F = 4.531$; $p = .04$) greater REA in the condition of the active right hand (LI = 36.81) as compared with the responses with the active left hand (LI = 14.58). For English

TABLE 1
Laterality Indices of Ear Advantage for the Two Languages
Depending on the Active Hand (Positive Values—Right-Ear
Advantage; Negative Values—Left-Ear Advantage)

	Active hand	
	Left	Right
Pooled responses		
Croatian	11.56	35.14
English	23.17	35.39
Responses to command pairs with both objects in the same hemispace		
Croatian	14.58	36.81
English	18.06	37.50

stimuli the difference was in the same direction and almost as large (37.50 vs 18.06), but has not reached significance ($F = 2.473$; $p > .05$) (Table 1b).

It may be concluded from this part of the experiment that there is indeed the activation-orienting effect for the stimuli in the native language. The forced use of the left hand causes greater activation of the right hemisphere, decreasing the size of the positive laterality index, i.e., diminishing the right-ear advantage. Since the right-ear advantage is so robust for the verbal stimuli in the native language, it is not surprising that there was no switch to the left-ear advantage with the active left hand. The fact that the right-ear advantage in the right-hand-active condition is still relatively low, indicates the absence of complete extinction of the less active hemisphere, but the difference between the two hemispheres is still significant. The nonsignificant presence of the same effect for the stimuli in the foreign language may be attributed to greater variability in responses to the stimuli in the language less well known, or (possibly in addition to) the fact, confirmed by numerous studies (Fabbro, 1999; Mildner, 1999) that the foreign language is more widely represented in the brain and is therefore not so susceptible to changes in activation of one or the other cerebral hemisphere.

For the 12 stimuli pairs where there was a choice between hemispaces the results show very interesting differences between the two languages. The two-way analysis of variance has shown no main effect of hand, but a significant main effect of language ($F = 77.490$; $p = .00$). The results are summarized in Table 2.

It may be clearly seen that for Croatian stimuli the subjects prefer to reach for the objects in the left hemispace (negative values), regardless of the active hand. To reiterate, this means that of the two competing commands to pick up the objects from

TABLE 2
Laterality Indices of Preferred Hemispace for the Two
Languages Depending on the Active Hand (Positive Values—
Preferred Right Hemispace; Negative Values—Preferred Left
Hemispace)

	Active hand	
	Left	Right
Croatian	−52.78	−43.06
English	12.50	9.72

the two different hemispaces they will significantly more often pick up the one on the left before the one on the right, regardless of the active hand or ear to which the command was presented. On the other hand, for the stimuli in English the subjects prefer the objects in the right hemispace (positive values), regardless of the active hand, although the degree of preference is smaller. Obviously, the effect of the hemispace is much stronger than the effect of the active hand. It is also clear now that the opposite hemispace preference for the two languages contaminated the pooled data (Table 1a), and it is therefore justified to analyze the effects separately.

Scarisbrick et al. (1987) also found no effect of hand on visual line bisection task and reported leftward error both in righ-handers and left-handers, which is in keeping with the fact that their task was visual and the stimuli nonverbal. Furthermore, Weintraub and Mesulam (1987) reported right-hemisphere dominance for the distribution of attention within the extrapersonal space (in brain damaged but also in control subjects), regardless of the modality of sensory input (visuomotor scanning or tactile exploration) or motor output. Fotiades et al. (1998) found that response times to stimuli in the left hemispace were faster than to those in the right—another piece of evidence of the right hemisphere dominance in directing attention. Applied to the data in this study, that would correspond to the negative laterality indices (preferred left hemispace—dominant right hemisphere). But, how do we explain the fact that the stimuli in this study were verbal, on the one hand, and that the same effect was not found for English?

Bradshaw et al. (1982) examined the relation between Braille reading and the left/right hemispace and concluded that left-hand/left-hemispace superiority in tactual tasks involving verbal stimuli occur only with novel, unfamiliar or perceptually degraded materials. Contrary to that, in this study the left hemispace superiority occurred with the more familiar (native language) stimuli. On the other hand, Mark and Heilman (1990) found that normal subjects were more apt to orient toward or be distracted by stimuli in the right hemispace. Reuter-Lorenz et al. (1990) reported attentional bias in the direction contralateral to the stimulated hemisphere and that the bias did not depend on the hemispatial position of the stimulus. The confirmation of that result in this study is clear for the stimuli where both objects were in the same space. However, in conditions of orienting conflict, they also found the rightward bias of the left hemisphere to be stronger than the other way around. Contrary to the results of those two studies dealing with visual nonverbal stimuli, in this study that was found only for English, but not for Croatian.

This study revealed a clear dissociation between the two languages with respect to the preferred hemispace. But, how can it be explained on the basis of what (we believe) is known about the cerebral representation of languages, activation-orienting and hemispace research? If, as it has been reported time and again (Loring et al., 1994; McCourt et al., 2000), the right hemisphere directs attention to both the right and the left hemispaces, whereas the left hemisphere directs attention only to the right hemispace, the preference for the right hemispace would be expected, expecially since the stimuli were verbal. Why then was this found only weakly for English, but not for Croatian? On the other hand, if we posit that the nature of the task is spatial because the subjects were asked, in fact, to locate the correct objects in space and pick them up, which is primarily an activity favoring the right-hemisphere, left-hemisphere preference is logical. After all, leftward error has been reported before (McCourt et al., 2000). But why was this not the case for English as well?

If, in accordance with part of the literature on the cerebral representation of languages in the bilingual brain (reviewed in Fabbro, 1999), we assume hemispheric differences in the representation of the two languages, the results are in the opposite direction. If there is such a difference, the first/native language is expected to be

represented in the left hemisphere and the second/foreign language in the right hemisphere. Within that framework the native language would prefer the right hemispace and the foreign language would prefer the left hemispace.

Clearly, the problem is not a simple one and at this point only a speculative solution may be offered. It may be difficult to characterize the nature of the task as to what extent it is spatial and to what extent verbal. If it is taken to be both at the same time, we are in the proper of concurrent tasks, and should investigate the nature of the load on one and/or the other hemisphere. If we assume that, while listening to the verbal commands presented auditorily the subject scans the space for the required objects, it is possible that the brain is optimally allocating its resources—left hemisphere monitoring the verbal task, right hemisphere the visuospatial. If the verbal task occupies the left hemisphere so much that it inhibits its ability to direct attention to the contralateral (right) hemispace, what we are left with is the preferred left hemispace as a consequence of the greater control of the right hemisphere. The difference in the results between the two languages may then be explained by the smaller load on the left hemisphere by the foreign language, leaving it (the left hemisphere) more ability/capacity to monitor the right hemispace. Taken together with the data from the part of the study where both objects referred to in the competing commands were in the same hemisphere, where there was a significant effect of the active hand for native language (Croatian) stimuli only, this may be taken as evidence in support of the previously reported results that the foreign language may be more bilaterally represented than the native language (Mildner, 1999). Given the gender differences in laterality found by some authors (Davidson et al., 2000) it is reasonable to expect that even more robust effects would be found with male subjects.

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Variability in Aphasic Patients' Response Times

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Response time studies of acquired language disorders are plagued by tremendous variability in patients' response times. In this brief report we demonstrate how variability itself may provide informative data. Lexical decision response times, generated by nine patients, illustrate how within-patient variability may estimate stability in cognitive dynamics.   © 2002 Elsevier Science (USA)

INTRODUCTION

Patients with brain damage often produce extremely variable response times in cognitive tasks. This creates methodological problems for comparisons between intact and deficit performances and potential difficulties for understanding the consequences of brain damage through response time (RT) data. The analysis of averaged RTs is the empirical backbone of cognitive psychology, but such analyses generally assume uniform variability across conditions (cf. McCloskey, 1993). Given this assumption, conventional analyses (i.e., ANOVA), have no entry point for factors like brain damage that affect response time variability. Thus, a theoretical approach that could more straightforwardly embrace changes in the variability of performance could prove useful for understanding patients' deficits.

In this brief report we present patient data to illustrate the problem of within-patient variability, and then demonstrate the potential for treating this variability as an informative dependent variable. In the lexical decision study that follows, we examined correct RTs to high and low frequency words, produced by patients who vary in their capacity to discriminate words from nonwords. Differences in patients' sensitivity to the distinction between words and nonwords appear systematically related to the variability of patients' word RTs. Also, correct RTs to low frequency words appear relatively less stable than RTs to high frequency words. Thus, changes in the variability of patients' RTs may be best considered a feature in the analyses, not a bug. We hope that a focus on intrinsic variability may eventually contribute to a better understanding of the problems that patients face.

PATIENT DESCRIPTIONS

Ten participants were enrolled in this study as part of an ongoing examination of language deficits following brain damage. All of the patients were right handed and all had damage to the left hemisphere. In all but one case, this damage was caused by a vascular incident. The exception was a patient JO whose damage was an unfortunate consequence of treatment for a tumor (described in Buchanan, McEwen, Westbury, &

Libben, 2001). The inclusion criteria were simply the presence of a language deficit
and the relative ability to make lexical decisions. One patient was eliminated by the
latter criterion; a patient TE showed too strong a bias for ''word'' responding—
100% ''word'' responses to words, and 41% ''word'' responses to nonwords. The
language deficit, itself, could be as minor as a subtle difficulty in word finding or as
major as an inability to produce spontaneous speech. However, all patients tested
could produce relatively clear pronunciations and were able to read aloud at least
some of the words presented in the study.

TASK DESCRIPTION

Patients performed lexical decisions to 150 words and 150 pronounceable non-
words. Key targets were 74 yoked word pairs in which one word was high-frequency
(100–20 per million) and the other was low-frequency (11–1 per million, Kuãera &
Francis, 1967). Each yoked pair was matched with respect to number of letters, first
phoneme (and almost always first letter), and they were otherwise single syllable
words similar in spelling and pronunciation. Words and nonwords were presented
one at a time, in fixed and identical randomized order to each patient. Items appeared
on a computer screen and remained on the screen until the patient responded. A plus
symbol (+) fixation stimulus appeared for 250 ms before each item. Responses were
made with the left hand on two keys of the computer keyboard. One key (the Ctrl
key) represented ''word'' responses while the other key (the Alt key) represented
''nonword'' responses. Patients were asked to respond as quickly as possible while
remaining accurate.

RESULTS

Moving from top to bottom, Table 1 presents accuracy data the corresponding
mean correct RTs. Every mean accuracy score, except RB's score to high frequency
words, is within the range of performance that we found for college students in a
pilot study using the same words (pilot accuracy: 64–89% for Low Frequency and
84–100% for High Frequency words). BC and LA produced mean RTs within the
range of intact performance (pilot mean RT: 696–905 ms for Low Frequency and
540–892 ms for High Frequency correct ''word'' responses). All other patients pro-
duced mean lexical decision times that were slower, usually much slower, than we

TABLE 1

Percent Correct Lexical Decisions to High and Low Frequency Words, and Nonwords, and
the Corresponding Mean Correct Response Time for Nine Aphasic Patients

	BC	BV	JM	JO	LA	MD	MH	RB	WM
Accuracy									
High Freq.	100	100	95	99	97	96	99	78	95
Low Freq.	97	91	80	88	92	73	78	65	65
Nonwords	93	83	93	91	97	89	97	76	93
Response Time									
High Freq.	880	1472	1319	1341	881	2751	1295	3113	966
Low Freq.	1043	1686	1903	1952	1140	3225	1558	3271	1268
Nonwords	1401	1823	2446	3236	1328	3217	1532	3854	1075

found for college student participants. Also, at least numerically, every patient's data replicate the standard finding that low frequency words yield lower accuracy and slower mean response times. In all but three patients these effects were reliable using conventional paired *t* tests on RT data. The exceptions to this were patients BV, MD, and RB whose mean RTs for low frequency words were not statistically slower than their mean RTs to high frequency words.

The analysis of mean RTs in the preceding *t* tests assumes a simple shift in mean RT without a change in variance. But RTs to low frequency words are reliably more variable than those to high frequency words, as estimated by *SD*s (a nonparametric sign test yields $z(9) = 2.0$, $p < .05$). An exclusive focus on mean RTs would fail to capture visible differences in the variability of patients' RTs. For example, on the basis of the results of the *t* tests one might be tempted to group BV, MD, and RB together as patients with similar deficits, reflected in insensitivity to word frequency. Analyses described next show that this grouping would be misleading.

Figure 1 presents scatter plots of correct ''word'' RTs to yoked high and low frequency words (both responses, to a yoked pair, must be correct to appear in the figure). The advantage of viewing the data in scatterplots is that we can actually see differences in variability across patients. Each panel presents a single patient's data and each plus sign, in a panel, corresponds to a pair of yoked item RTs; the low-frequency word's RT is indexed on the *X* axis, and its yoked high-frequency word's RT is indexed on the *Y* axis. The diagonal line represents equal RTs. Points below the diagonal line tell us that the RT to the low frequency word was slower than the
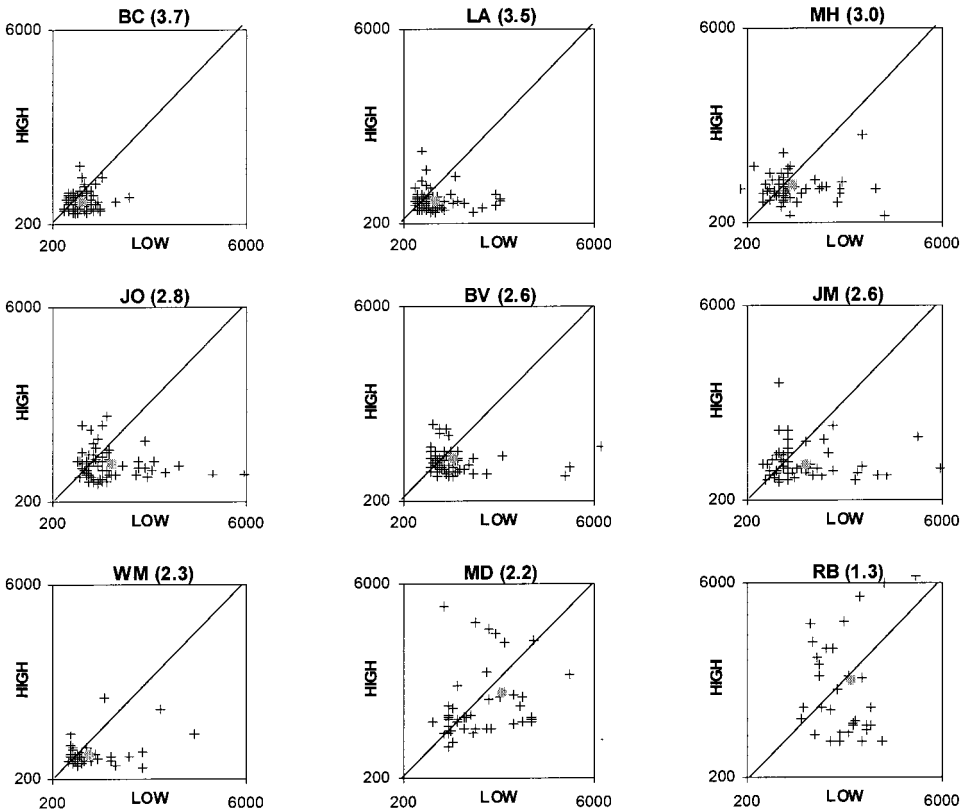

FIG. 1. Correct response times to yoked high and low frequency words.

RT to the yoked high frequency word. The gray dot indexes the mean of low fre-
quency words' RTs on the *X* axis and the mean of high frequency words' RTs on
the *Y* axis. Thus, a hypothetical word frequency effect, assuming uniform variability,
would appear as a circular symmetrical clump of points, with the gray dot at the
center of the clump, shifted slightly below the equal RT diagonal. But symmetrical
clumps never occur. In the present data, the primary source of the word frequency
effect is a difference in variability, as more extreme slow RTs accrue to low frequency
words (e.g., the fastest paired RTs cluster very close, or on top of, the equal-times
diagonal).

The scatter plots in the Fig. 1 provide information about variability in individual
patient's performance, seen here in the extent to which points spread out along the
X and *Y* axes. The scatter plots are ordered—left to right, and top to bottom—by a
value, d′, that estimates a patient's sensitivity to the distinction between words and
nonwords. The value of d′, used to rank the panels, is given next to the patient's
initials. The statistic d′ was computed from standardized measures of the proportion
of incorrect ''word'' responses to nonwords (the *false alarm* rate) and the proportion
of correct ''word'' responses to words (the *hit* rate).

The empirical point, that these panels illustrate, can be seen in a visual analysis.
Notice how patients BC and LA, at the top of the figure, present fairly dense sets of
points clustered toward the bottom-left (fast times) of the panel. As we move down
the figure, however, there is a marked tendency for the points to spread, initially
along the *X* axis, but eventually on both axes, as the gray dot moves toward the top-
right (slow times) of panels. Even a cutoff of 6000 ms cannot contain the full extent
of the spread in extreme cases. There are 20 points (forty yoked RTs) not pictured,
that were outside the 6000 ms cutoff, mostly from patients MD and RB.

The rank order correlation of each patient's d′ with the variability of their RTs
(estimated by the *SD*) is statistically reliable for high frequency words and approaches
statistical reliability for the more unstable RTs to low frequency words (correlation
between d′ and patients SD_{RT}: high frequency words, $r(9) = -0.75$, $p < .05$; low
frequency words, $r(9) = 0.63$, $p < .07$). Variability is systematically related to patient
characteristics.

DISCUSSION

We examined whether variability in patient RTs could provide us with insight into
how patients are impaired by brain damage. The departure point, for this discussion
is the methodological dilemma of systematic differences in variance of patient RTs
versus analyses of mean RTs that assume uniform variability. As the dilemma re-
veals, there is no entry point in the conventional analysis for changes in variability
due to brain damage. Natural differences in variability, typical of deficit perfor-
mances, violate the *a priori* assumptions required to justify conventional analyses.
Worse yet, this blind spot in conventional analyses may hide meaningful differences
between patients. BV's RT data make this point nicely: Conventional *t* tests would
group BV with RB and MD, who are also insensitive to word frequency, but the
scatter plots clearly indicate that BV is not impaired in the same way as RB and
MD.

The extreme spread toward slow RTs is the most prominent feature in the majority
of these patients' data. But the conventional blind spot would force us to assume
that extreme RTs are not meaningful. In conventional analyses, extreme slow RTs
are attributed to nuisance factors, such as a lapse in attention or an eye blink, and

trimmed from the data. Visual inspection of each patient's data, however, shows that the present "frequency effects" are actually mostly due to extreme slow RTs to low frequency words. Trimming, in this case, could impact mean RTs as much, or more, than any typical "word frequency effect" (see Ulrich & Miller, 1994, for extensive discussion of how trimming changes mean effects). Most important, were we to ignore that slow RTs accrue in patients' data, we would ignore their most salient deviation from intact performance.

Variability in response time can serve as an index of stability (compare Hays, 1994). In that regard, cognitive theorists and neuroscientists have proposed that relative stability of "attractor states" distinguishes familiar from unfamiliar stimuli (Lewenstein & Nowak, 1989a, 1989b; Skarda & Freeman, 1987). This hypothesis could also be extended to explain how we distinguish familiar (*word*) versus unfamiliar (*nonword*) letter strings in lexical decision (Gibbs & Van Orden, 1998; Van Orden & Goldinger, 1994). Thus, in general, a primary source of variability in response times is the intrinsic stability of interacting dynamic processes, that must cohere in a sufficiently stable dynamic state for a response (Van Orden, Pennington, & Stone, 2001). This general hypothesis treats task responses like attractor states of neural network models (e.g., Kawamoto, 1993; Cree, McRae, & McNorgan, 1999; Masson, 1995, Plaut & Shallice, 1993). In a neural network model, less intrinsically stable "word dynamics" require more iterations to achieve attractor "response" states (the number of iterations is the neural network equivalent of response time). But how are we to think about stability as a way of understanding patients' deficits?

The present analysis provides us with two sources of information regarding patient deficits. Variability in patients' RTs is systematically related to sensitivity to the word versus nonword distinction. Thus a reduction in response stability, indicated by an increase in RT variability, appears as a hallmark symptom of brain damage (not a nuisance variable). A related view is discussed in greater detail in Farrar and Van Orden (2001), who simulated characteristic naming errors of acquired dyslexias (e.g., surface dyslexia is characterized by the regularization error, in which PINT is read aloud to rhyme with MINT). In these simulations, the intrinsic stability of a pronunciation predicts its vulnerability to simulated lesions. Likewise, the frequency effect on variability, in the present study, may imply that intrinsically more stable "word dynamics" to high frequency words are less vulnerable to lesions.

Aspects of nonlinear dynamical systems theory, and analyses of stability, barely hinted at in this brief report, could make an important contribution to our understanding of brain damage and its impact on cognitive functioning. Farrar and Van Orden's (2001) simulations illustrate how the stability of a model's pronunciation can change continuously with only superficial consequences for pronunciation time, but a catastrophic change will occur when some critical value is met. Tiny quantitative changes to a dynamical system can yield qualitative changes in behavioral options. In such a system behavioral possibilities may become highly unstable, or even disappear, only to reappear in a new context. This is perhaps the most intriguing aspect of this way of thinking about brain damage; we may better understand the apparent fluidity of patient's deficits. Neurological patients commonly experience more difficulties in some contexts than in others, for example, and this can be understood if one considers that some contexts entail more supportive constraints than others. Small changes in contextual support could induce the appearance and disappearance of functional competence (Van Orden, Jansen op de Haar, & Bosman, 1997). The context sensitivity of functional competence also underscores the essential point of this article. Variability in functional competence is a symptom of brain damage and not a bug in the analysis.

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