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A Longitudinal Study of the Performance of the Elderly and Young on the Tower of Hanoi Puzzle and Rey Recall

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Normal performance on the Tower of Hanoi puzzle by amnesic patients has been taken as support for viewing this problem solving task as having a nondeclarative memory component. Individuals in each decade of life between the 20s and 80s were asked to solve this puzzle four times in four sessions with intersession intervals from 1 to 7 days (Davis & Keller, 1998). Participants in their 70s and 80s were significantly impaired compared to participants in their 20s and 30s. The elderly were also significantly impaired on five immediate trials of a 15 words verbal recall test. Participants were readministered these tests an average of 6.6 years later for the elderly ($n = 12$) and 7.7 years later for the young ($n = 11$). For the Tower of Hanoi, the performance of the elderly, but not the young individuals, was significantly poorer than their original performance. For the verbal recall test, no significant change over time was detected for the young or elderly participants. These findings support the view that some nondeclarative and/or problem solving tasks demonstrate as great or greater decline with age than some declarative tasks.

Performance on declarative memory tests such as recall and recognition is typically impaired in amnesic patients (Squire & Kandel, 1999) and the elderly (Davis et al., 1990; Light & Singh, 1987). Conversely, ‘‘nondeclarative memory,’’ memory that is not necessarily mediated by conscious recollection and is often exhibited by skill acquisition and priming, is frequently unimpaired in amnesic patients and either unimpaired or only slightly impaired in the elderly (Howard, 1996; Light, Singh, & Capps, 1986; Schacter & Graf, 1986). Dissociations of memory in the elderly in well documented, but few studies have assessed declarative and nondeclarative memory changes in adults' performance over time.

The current study provides a longitudinal assessment of age-related changes on a task thought to have a nondeclarative component and a prototypical declarative memory task. Specifically, Rey's Auditory Verbal Learning Test (RAVLT) (Lezak, 1983) was utilized to assess declarative memory, and the Tower of Hanoi puzzle (Simon, 1975) was used to assess nondeclarative memory in both young and elderly participants. The Tower of Hanoi puzzle has been viewed as a nondeclarative task because of the reported normal learning of the creative solution strategy by amnesic patients (Cohen, 1984). The original administration of these tests and findings are reported as part of the norms for the Colorado Assessment Tests (Davis & Keller, 1998). The RAVLT and Tower of Hanoi puzzle were readministered approximately 6 to 7 years later.

Method

Participants. Twelve older participants and 11 young participants who had completed the RAVLT and the Tower of Hanoi puzzle previously agreed to participate in the current study. An average of 6.5 years had passed since the original testing of the older participants and 7.8 years has passed since the original testing of the

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young participants. The older participants were originally recruited from senior citizen's groups in Colorado Springs, Colorado. Young volunteer participants were originally recruited from undergraduate courses at the University of Colorado at Colorado Springs. The older participants had an average age of 81.0 $\pm$ 6.6 years (range of 70 to 91 years of age), and the young participants had an average age of 32.4 $\pm$ 8.4 years (range of 25 to 47 years of age) at the time of the current study. All participants were in independent living situations and reported they were in good health during the previous and current study.

The elderly participants had significantly higher levels of education (16.7 $\pm$ 2.2 years) than the young participants (13.8 $\pm$ 1.0) at the time of their recruitment, $F(1.21) = 16.0$, $p = .001$.

Tests and procedures. Neuropsychological and psychometric tests were completed in a quiet testing room at the University of Colorado at Colorado Springs or in a quiet room of the participant's home. All participants were originally administered (a) 16 trials of the Tower of Hanoi puzzle, (b) the recall version of RAVLT, and (c) seven subtests of the Weschler Adult Intelligence Scale Revised (WAIS-R) (Weschler, 1981). Older and young participants were readministered four trials of the Tower of Hanoi puzzle and the recall version of the RAVLT.

WAIS-R. Participants were administered seven subtests of the WAIS-R. Three subtests were performance subscales (block design, object assembly, and digit symbol), and four subtests were verbal subscales (information, digit span, vocabulary, and similarities). Full-scale IQ scores were derived using Wechsler's (1981) prorating method.

Tower of Hanoi puzzle. A minimum of four blocks of the five-ring Tower of Hanoi puzzle, consisting of four trials in each block, was administered following the protocol outlined in Davis and Keller (1998). Specifically, participants attempted four solutions of a five-ring Tower of Hanoi puzzle with five different sized rings initially arranged on the left peg of three pegs, the largest ring on the bottom and the smallest ring on the top. Subjects were instructed to move the rings to the peg on the right in as few as moves as possible. Subjects were told they could move only one ring at a time and never place a larger ring on top of a smaller ring. The minimum number of moves for an optimal solution is 31 moves. The experimenter sat behind to participant to avoid any nonverbal cues and started a new trial after goal achievement or 120 moves.

RAVLT. Five trials of Rey's AVLT consisting of 15 common nouns randomly ordered in each trial were presented orally at a rate of one word every 2 s. Participants were instructed to listen carefully to each lift of words. After the list was completed, they were asked to recall as many words from the list as they could remember. A 20-s intertrial interval was given after each immediate recall test in Trials 1–5. A 20-min delay was given after the fifth trial, during which the participants were engaged in conversation or worked on the Tower of Hanoi. After 20 min, participants were asked to recall as many words as they could remember.

Results

WAIS-R. Performance of the elderly participants on the WAIS-R performance IQ was not significantly different than the performance of the young participants, $F(1, 21) < 1.00$, $p = .41$. However, elderly participants did achieve significantly higher WAIS-R full-scale IQ and verbal IQ scores than younger participants, $F(1.21) = 4.3$, $p = .05$, and $F(1, 21) = 6.0$, $p = .025$. The means ($\pm$SD) were the following: Verbal young 112 $\pm$ 11, Verbal elderly 123 $\pm$ 11; Performance young 110 $\pm$ 11, Performance elderly 114 $\pm$ 11; and Full young 113 $\pm$ 9, Full Elderly 122 $\pm$ 12.

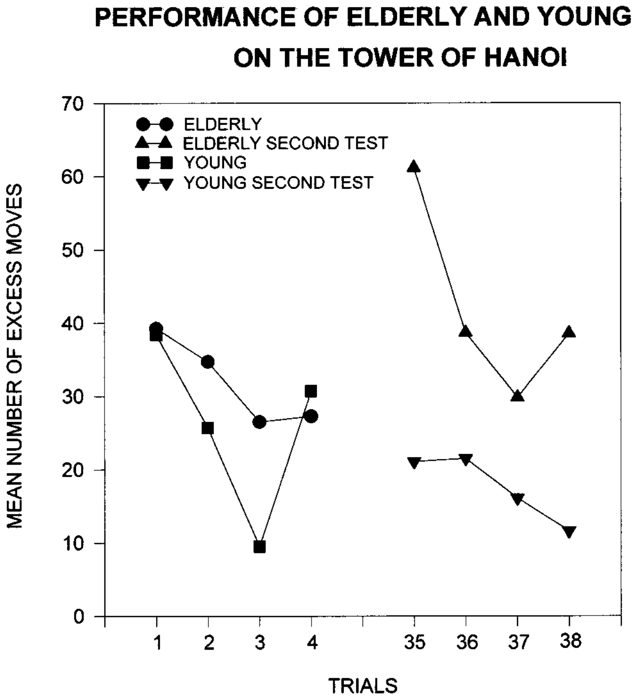

FIG. 1. Mean excess moves on the Tower of Hanoi puzzle (all moves greater than minimum 31 moves for optimal solution) for young and elderly participants at an initial test and a subsequent test 6–7 years later.

Tower of Hanoi puzzle. A 2 (age condition) by 2 (session) by 4 (trial) mixed design ANOVA was performed on the mean number of excess moves required to solve the puzzle. Figure 1 shows the mean number of excess moves made by the young and elderly participants. The analysis yielded a significant main effect of trials, $F(3, 63) = 5.3$, $p = .002$, with participants decreasing the number of excess moves required to solve the puzzle. A significant interaction of age and session was detected, $F(1.21) = 8.2$, $p = .01$. Post hoc analyses on age condition at each session detected no initial difference between age groups, but the young subjects made significantly fewer excess moves at the second session ($p = .005$). Post hoc analyses on sessions for each age group showed no difference across sessions for the young participants, but the elderly demonstrated a significant decline in performance in the second session ($p = .015$).

RAVLT. A 2 (age condition) by 2 (test session) by 5 (trials) mixed design ANOVA and a 2(age) by 2 (test session) by 2 (fifth recall trial and 20-min delayed recall trial) mixed design ANOVA were performed on the mean number of words recalled for the five immediate trials and the delay trial. Figure 2 shows the mean number of words recalled per trial by the young and elderly participants The elderly participants recalled significantly fewer words than the young on the immediate recall trials of the RAVLT, $F(1, 19) = 27.7$, $p = .001$, and on a delayed recall trial, $F(1, 19) = 19.2$, $p = .001$. However, no significant change over time was detected in performance on RAVLT for young and elderly participants ($p > .25$ in both cases). No significant interactions were detected.

Discussion

Although elderly participants had poorer performance than the young on Rey's Auditory Verbal Learning Test, neither elderly nor young showed a decline in perfor-

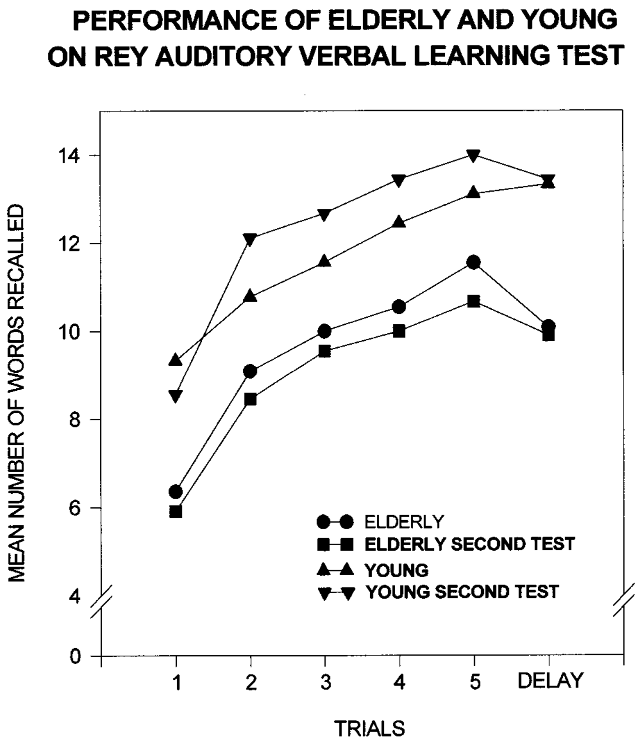

FIG. 2. Mean number of words recalled on the RAVLT by young and elderly participants at an initial test and a subsequent test 6–7 years later.

mance from their original testing. In the current study the elderly and young participants' ability to perform a declarative memory task remained stable over time. This is not always the case. Davis, Trussell, and Klebe (submitted) found a decline on the RAVLT by elderly subjects in a 10-year longitudinal study.

In contrast, elderly participants demonstrated a marked decline in performance on the Tower of Hanoi puzzle over the 7-year interval. Young participants' performance on this task did not differ over time. Again, this is not always the case for tasks that have been classified as assessing nondeclarative memory. Davis et al. (submitted) found no decline by the elderly on a word-stem priming test in a 10-year longitudinal study.

Initial studies of aging and nondeclarative memory generally reported declarative memory deficits accompanied by a relative sparing of nondeclarative memory in the elderly (Light & Singh, 1987). When studies began to appear reporting impairment on nondeclarative tasks by the elderly (Chiarello & Hoyer, 1988; Davis et al., 1990) it was suggested that their impairments in nondeclarative was relatively small when compared with their declarative deficits (Howard, 1996). More recently, it has been suggested that nondeclarative tasks with conceptual components are more susceptible to age-related effects than tasks with mainly perceptual components (Gabrielle, 1998). Burke (1992) has suggested that nondeclarative tasks requiring the establishment of new associations may be more susceptible to age effects. The current study showed elderly participants' performance on a declarative memory task remained intact over time, whereas elderly participants' performance on a nondeclarative memory task declined over time. Woodruff-Pak and Finkbiner (1995) report a large deficit by the elderly on an eye blink classical conditioning task, a task used to assess nondeclarative learning and memory. Davis and Bernstein (1992) reported that the elderly demonstrate a deficit on a word-stem priming task that was as large as their deficit on a declarative recall test. Thus, several studies in addition to the current study support the conclusion that nondeclarative memory is not always spared by the aging process and in some cases shows similar or greater decline than the deficit observed for declarative memory.

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A Ten-Year Longitudinal Examination of Repetition Priming, Incidental Recall, Free Recall, and Recognition in Young and Elderly

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The effects of age and time on nondeclarative and declarative memory in young and elderly were examined in a 10-year longitudinal study using tests of word-stem priming, incidental recall, free recall, and recognition. The elderly were significantly impaired on all tests, but no reliable longitudinal decrement by the elderly was detected for priming, incidental recall, or recognition. The elderly demonstrated a significant longitudinal decline in declarative memory as assessed by a test of free recall. While nondeclarative memory declines with age, the longitudinal findings are consistent with the view that declarative memory is more susceptible to the effects of aging.

The past decade has been a period of intense research into how different memory systems may be differentially affected by age. Declarative memory, a domain of memory associated with conscious recollection and usually assessed with recall or recognition tests (Squire, 1987), is consistently impaired in the elderly (Poon, 1985). Nondeclarative memory, a domain of memory that does not require conscious recollection and that can be examined using tasks that do not rely on deliberate conscious awareness (Squire, 1987), is variously reported to be intact (for review see Howard & Wiggs, 1993) or impaired (for review see Davis & Bernstein, 1992) in the elderly.

Repetition priming has been the task most frequently used for assessing nondeclarative memory function in the elderly. Early studies of repetition priming reported no age-related change in priming but impaired declarative memory (e.g., Light & Singh, 1987). Impaired repetition priming was reported for the elderly in later studies using larger sample sizes (Chiarello & Hoyer, 1988) or older groups of participants (Davis et al., 1990). Recently, the application of the metaanalysis technique to studies of repetition priming confirmed the finding of age-related decline in priming, albeit a smaller age-related decrement than occurs for declarative memory (La Voie & Light, 1994).

Approximately 10 years ago, repetition priming, incidental recall, recognition, and free recall were examined in individuals in each decade of life between the 20s and 80s (Davis et al., 1990). We now report a 10-year longitudinal examination of performance on declarative and nondeclarative tasks by young (currently less than 65 years of age) and elderly individuals (currently older than 65 years of age) from this original study.

Method

Participants. The participants in the present study are a subset of the participants from the study of Davis et al. (1990). In the original study, the total sample size was 147. For the present study, attempts were made to locate as many of the original participants as possible. Thirty-eight of the original participants were located within the local area. Eighteen percent of the original participants who were 55 or younger were retested; 25% of the original participants who were 56 or older participated in the retesting. It is suspected that death is the main reason for attrition in the elderly, and relocation or marriage (and name change for females) is the main reasons for attrition in the younger group. All of the participants were living independently, described themselves as in fair to good health, were taking no medications they believed might affected their mental functioning, had no history of head injury or psychiatric disorder, and volunteered for the follow-up testing. Based on the neuropsychological tests administered to participants in the Davis et al. study, there was no indication that the current sample of elderly differed from those elderly unavailable for retest. No differences were detected in the initial frontal lobe scores and IQ scores for the elderly that participated in this study and those that could not be located.

Twenty participants, averaging 43.3 (SD = 11.43) years of age (range 26–64), comprised the young group. In the original study, these participants averaged 33.2 years of age (SD = 11.38; range 18–54). Eighteen participants, averaging 81.3 (SD = 7.46) years of age (range 70–95) made up the older group. In the original study, these participants averaged 71.5 (SD = 7.22) years of age (range 61–86).

Procedure. Nondeclarative memory was assessed via a word-stem priming test described previously in detail (Davis et al., 1990). Briefly, word-stem priming involved rating the pleasantness of 15 concrete nouns. Participants then completed 20 three-letter word stems with the first word that came to mind. Ten of the stems could be completed with previously rated words and 10 could be completed with unrated words. The priming score was the mean percent of rated words correctly completed minus the mean percentage of baseline words correctly completed with target words. Participants were next shown a new list of 15 words to be rated. Participants then completed an incidental recall for the list just rated. Participants next rated 15 new words and completed a forced choice recognition test of rated and distractor words. Finally, free recall was assessed with a version of the Rey Auditory Verbal Learning Test. There were five immediate trials followed 20 min later by a single delay trial.

Results

Word-stem priming. An ANOVA performed on priming scores revealed a significant effect of age, $F(1, 35) = 6.11$, $p = .02$. The young ($M = 43.00$, $SEM = 3.43$) demonstrated significantly higher priming scores than the elderly ($M = 28.67$, $SEM = 4.26$). There was also a significant effect of time, $F(1, 35) = 4.15$, $p = .049$. Time 2 priming scores ($M = 39.12$, $SEM = 3.07$) were significantly higher than Time 1 priming scores ($M = 32.55$, $SEM = 3.55$). There was not a significant interaction between time and age, $F(1, 35) = 1.48$, $p = .23$ (Fig. 1).

Incidental recall. An ANOVA performed on the incidental recall scores detected a significant effect of age, $F(1, 35) = 10.67$, $p = .002$. Thus, for incidental recall, the young recalled more words than the elderly. There was no significant effect for time, $F(1, 35) = 1.46$, $p = .24$, nor a significant interaction between age and time, $F(1, 35) = 1.37$, $p = .25$.

Recognition. An ANOVA performed on recognition scores revealed a significant effect of age, $F(1, 35) = 14.87$, $p < .001$, with the younger participants ($M = 98.63$, $SEM = 1.18$) having higher recognition scores than the older participants ($M = 91.91$,

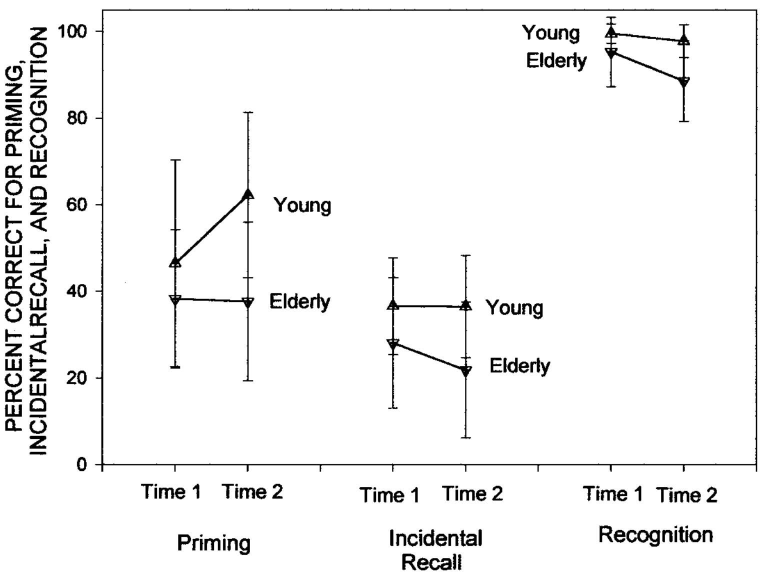

FIG. 1. The three plots from left to right are priming, incidental recall, and recognition scores for the young and the elderly, respectively.

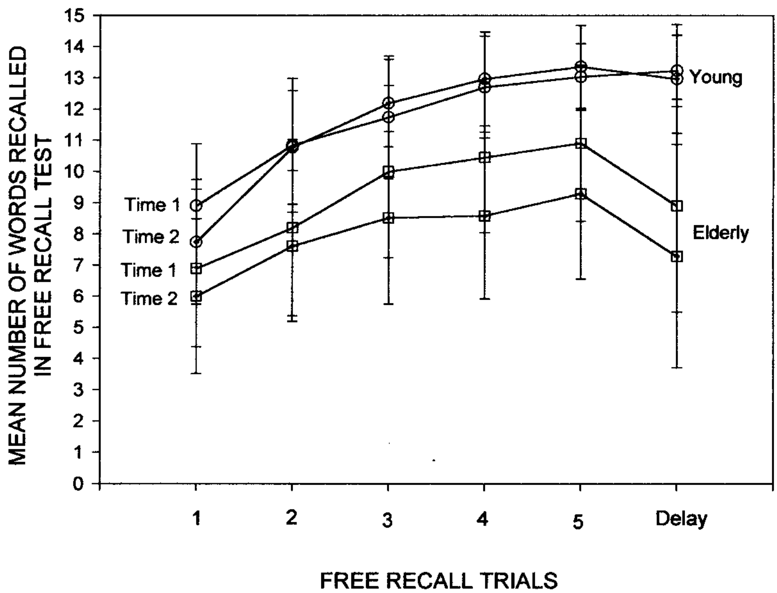

FIG. 2. The plots are the mean number of words recalled per trial on the free recall test for young and elderly participants.

SEM = 1.28). There was also a significant effect of time, $F(1, 35) = 14.04$, $p < .001$, with Time 1 scores ($M = 97.40$, $SEM = 0.93$) having higher scores than Time 2 scores ($M = 93.14$, $SEM = 1.14$). There was also a significant age by time interaction, $F(1, 35) = 4.87$, $p = .03$. To further investigate this interaction, the effects of time for each age group are analyzed using a dependent *t* test at a significance level of .025. The younger group shows no significant change in scores across time, $t(19) = 1.68$, $p = .110$, while the elderly group shows a significant decline in scores from Time 1 ($M = 95.29$, $SEM = 1.94$) to Time 2 ($M = 88.53$, $SEM = 2.26$), $t(16) = 3.16$, $p = .006$.

Free recall. An ANOVA performed on the number of words recalled detected a significant effect of age, $F(1, 28) = 20.55$, $p < .001$, a significant effect of time, $F(1, 28) = 6.44$, $p = .02$, and a significant effect of trials, $F(5, 140) = 92.70$, $p < .001$. There was a significant age by trials interaction, $F(5, 140) = 10.35$, $p < .001$, and a significant time by age interaction, $F(1, 28) = 5.15$, $p = .03$. No time by trials interaction was detected, $F(5, 140) = 1.03$, $p = .40$. A significant time by trials by age interaction was detected, $F(5, 140) = 3.28$, $p = .008$. To clarify the changes in performance, the three-way interaction was further analyzed by completing simple interaction effects for each age group (Fig. 2).

Two 2 × 6 ANOVAs were performed on the trials at the two test times for the young and elderly separately. For the young, no significant effect of time was detected, $F(1, 14) = .09$, $p = .77$, but a significant effect of trials, $F(5, 70) = 79.11$, $p < .001$, and a significant time by trials interaction, $F(5, 70) = 2.98$, $p = .017$, were detected. Paired *t*-tests on Time 1 and Time 2 performance at each trial were used to analyze this interaction. The only significant difference was with Time 1 having a higher mean than Time 2 on the first trial, $t(14) = 4.29$, $p = .001$. No other trials had a significant difference across time.

The 2 × 6 ANOVA performed on the elderly group revealed a significant difference from Time 1 to Time 2, $F(1, 14) = 7.125$, $p = .02$, with the elderly performing significantly lower across time. A significant effect was found for trials, $F(5, 70) =$

30.32, $p < .001$; however, no significant interaction was detected, $F(5, 70) = 1.54$, $p = .19$. Thus, the elderly demonstrate a clear decline in the free recall test from Time 1 to Time 2.

It was surprising to find no clear and convincing decline in the elderly's performance on word-stem priming or incidental recall over the 10-year period. The age by time interaction for recognition was not considered reliable evidence for differential decline by the elderly because of a possible ceiling effect for the young. For all measures, there were fairly large amounts of variability with unequal variances across groups and times. Accordingly, to decrease variability among the scores, the scores for each test were ranked and separate ANOVAs were performed which compared the young and old group's ranked priming, incidental recall, and recognition scores. These analyses confirm the previously stated findings in terms of detecting a significant effect of age on all three tests. However, a significant age by time interaction was detected for recognition scores and is consistent with the possibility of differential decline on this test by the elderly.

Discussion

This report is the first longitudinal study that assesses declarative and nondeclarative memory in the young and elderly over a 10-year period. The results verify Davis et al.'s (1990) findings of impaired priming, incidental recall, and recognition in 70 and 80 year olds. Perhaps the most surprising aspect of this study is the lack of a clear decline in the elderly's performance on all tests except the free recall over the 10-year span of this study. For priming, the lack of decline in performance across time, as well as a lack of an interaction effect, is consistent with Davis et al.'s cross-sectional finding of no decline in priming in individuals from the 70s to the 80s. Indeed, a reasonable interpretation may be that the priming scores obtained in this study and Davis et al.'s study represent a floor effect for the independently living elderly in their 70s and 80s.

Conversely, the interaction that was detected in the recognition scores is probably due to ceiling effects. There was little variance in the scores of the young group and their mean recognition scores clearly indicate a ceiling effect. Even though significant time differences were found in priming and recognition, no reliable longitudinal decline in the elderly's performance relative to young subjects on any of the three tests, priming, incidental recall, or recognition, can be assumed.

In contrast, the free recall test revealed a change in declarative memory due to a decline in the elderly's recall performance over the 10 years. The young participants' performance on recall at Time 2 was virtually identical to their original performance with the exception of the initial trial. An analysis of the elderly's performance on free recall at Time 1 and Time 2 clearly indicated a decline, although performance across trials was similar at each time period.

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The ''Temporal Processing Deficit'' Hypothesis in Dyslexia: New Experimental Evidence

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The notion that developmental dyslexia may result from a general, nonspecific, defect in perceiving rapidly changing auditory signals is a current subject of debate (so-called ''temporal processing deficit'' hypothesis). Thirteen phonological dyslexics (age 1013 years) and 10 controls matched for chronological and reading age were compared on a temporal order judgment (TOJ) task using the succession of two consonants (/p/-/s/) within a cluster. In order to test the relevance of the temporal deficit hypothesis, the task also included two additional conditions where either the two stimuli were artificially slowed or the interstimulus interval was expanded. As expected, the TOJ performance was significantly poorer in dyslexics than in controls. Moreover, in the ''slowed speech'' condition dyslexics' performance improved to reach the normal controls' level, whereas no significant improvement occurred when increasing the interstimulus interval. Finally dyslexics' performances, especially on the slowed condition, were found correlated with several tests of phonological processing (phoneme deletion, rhyme judgment, and nonword spelling tasks). These results lend support to the general temporal deficit theory of dyslexia.

Introduction

Impairment in phonological processes, widely recognized as central to developmental dyslexia, may result from a general, nonspecific, defect in perceiving rapidly changing auditory signals. This notion has gained recent interest after the demonstration that manipulating the temporal characteristics of acoustic stimuli may improve language performances in various developmental speech and/or reading problems (Tallal et al., 1996; Merzenich et al., 1996; Habib et al., 1999). This theory was first put forward by Tallal and her collaborators (Tallal & Piercy, 1973; Tallal, 1980) following the observation that children with language learning impairment failed to perform temporal order judgment (TOJ) tasks when interstimuli interval were short (20 to 40 ms) but did not differ from normal controls for longer intervals (80 to 120 ms). Despite significant evidence accumulated since in favor of this theory (for a review, Farmer & Klein, 1995), others have objected that the problem is not acoustic but rather is linguistic in nature (Mody et al., 1997).

In the present paper, we aimed to test dyslexic children on a TOJ task using CCV syllables, a common syllable structure in French where many dyslexic children experience special difficulties and exhibit a tendency to randomly modify the consonant cluster. One unresolved issue concerns the relationship between stimulus duration and interstimulus interval, which led us to manipulate these two variables in the experimental setting. Finally, we also wanted to investigate whether phonological impairment, supposed to be crucial to impaired reading process in dyslexia—namely difficulties in phonemic parsing, assembly, and categorization—and usually demonstrated in dyslexic children, is or not related to such a general deficit in temporal processing of auditory stimuli.

Subjects and Methods

The subjects were 13 phonologically dyslexic children (11 boys and 2 girls) ranging in age from 9.8 to 13.7 years and 10 normal readers (boys) ranging in age from 11.5 to 13 years. The dyslexic subjects were attending a center specializing in the treatment of dyslexia. They were selected on the basis of the criteria generally used to diagnose phonological dyslexia, namely, a normal IQ, no neurological, auditory, or visual disorders of any kind; no attention deficit; and a 2-year lag in reading ability (Alouette Test, P. Lefavrais). The normal reading subjects were attending junior high school and were recruited by means of a questionnaire that made sure the children had no personal or family history of a speech acquisition disorder. As a preliminary step, the subjects took four phonological awareness tests: rhyme judgments, deletion of first phoneme, dictation of simple syllable nonsense words, and dictation of complex syllable nonsense words. Significantly impaired performance to these tasks in dyslexics compared to controls (ANOVA, $27.7 \cdot F \cdot 108.965$, $p < .01$, for the four tests) confirmed the diagnosis of phonological dyslexia (Table 1).

The consonant clusters ps and sp were chosen because, unlike the cluster dr, for example, they have the advantage of being noises without formant information and thus without formant transitions. Furthermore, ps and sp are both legal clusters in French, which made it possible to present the stimuli in either order. The clusters were inserted in the vocalic context a-a so as to avoid acoustic artifacts (truncation of the burst in the ps cluster, poor audibility of the [s]). None of the resulting stimuli (apsa, aspa, apEsa, asEpa) were words, so they necessarily activated the phonological channel and avoided lexical access. The stimuli were recorded in an anechoic chamber spoken by a natural male voice and then digitized on a Sun computer.

In all three experiments, the stimuli were presented in random order. The subjects heard the stimuli through headphones and had to answer by pressing two designated keys on the computer keyboard in the order they thought they heard the two consonants. To lighten the memory load for the subject, the keyboard was covered in such a way that only the letters P and S were visible.

In the first experiment, consonant order was judged in a CCV syllable. A block of 60 temporally unaltered stimuli was generated (30 aspa and 30 apsa). In the second experiment, the two consonants were altered in two ways. In Block A, both sounds retained their intrinsic duration but they were separated by the neutral French vowel

TABLE 1
Results of Phonological Awareness Tests in Controls and Dyslexics

	Rhyme judgment		First phoneme deletion		Simple nonword spelling		Complex nonword spelling	
	Dyslexics	Controls	Dyslexics	Controls	Dyslexics	Controls	Dyslexics	controls
Mean	81.08	98.18	52.15	96.46	42.00	99.55	26.62	98.18
SD	10.57	2.09	22.85	2.81	26.33	1.61	22.74	1.62

E (schwa) so that both stimuli had a simple syllable onset; the total duration of the pEs or sEp was 210 ms. In Block B, the two sounds were lengthened to 210 ms (to match block A stimulus duration) but they still formed a single unit; the syllable onset was thus a consonant cluster. Then the two blocks were combined to form one 120-stimulus block containing 30 aspa, 30 apsa, 30 apEsa, and 30 asEpa. For the third experiment, we generated a block of 60 temporally unaltered stimuli (30 aspa and 30 apsa) and a block of 60 temporally altered stimuli containing 30 aspa and 30 apsa in which the ps (or the sp) was lengthened from its normal duration of 140 ms to twice that length (280 ms).

All three experiments were run on a Macintosh 7200 computer using Psyscope software.

Results

Experiment 1: event order judgments. This first condition served as a controls condition and confirmed that dyslexics are significantly poorer than controls at judging the temporal order of two phonemes within a cluster.

The difference between the two subject groups was highly significant (ANOVA, $F = 22.082$, $p = .0001$). Dyslexic children did indeed exhibit a consonant order judgment deficit, even for these consonants which are phonetically very different, [p] and [s] differing by more than one phonetic feature. This observation may contribute to the particular difficulty CCV clusters represent to French dyslexics as demonstrated by typical errors in reading or written transcription of such clusters.

Experiment 2: comparison of event order judgments of CCV vs CVCV situations (Fig. 1). For both controls and dyslexics, the two-factor ANOVA (subject group and condition) yielded a nonsignificant difference between the two tasks (condition, $F = .929$, $p = .3404$; condition $\times$ group interaction, $F = 1.129$, $p = .2939$).

Thus, discriminating two consecutive consonants in a complex syllabic structure appears to be just as difficult for dyslexics as in a simple syllabic structure. Since, the two conditions were otherwise equal from a duration standpoint, it can be concluded that stimulus spacing is not a pertinent variable as to the aptitude of dyslexic subjects to judge of their order.

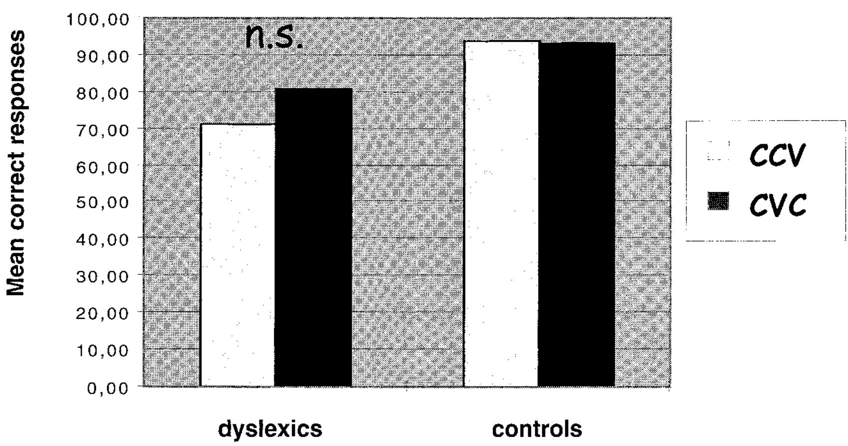

FIG. 1. Experiment 2. Comparison between dyslexics' and controls' performance in two temporal order judgment (TOJ) tasks on consonant succession (/$\overline{\text{ps}}$/) in two different conditions, either CCV cluster or two-syllable structure (CVCV). Dyslexics do not significantly improve their performance on the seemingly easier CVCV structure.

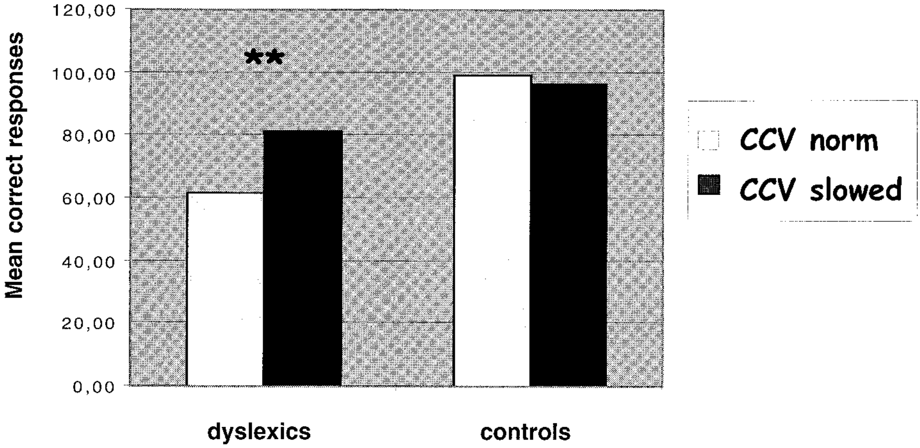

FIG. 2. Experiment 3. Comparison between dyslexics and controls on a TOJ task involving a CCV structure with either natural speech or temporally expanded duration of the consonants. Dyslexics significantly improve their performance in the acoustically modified version of the task.

Experiment 3: effect of stimulus lengthening on event order judgments (Fig. 2). The subject group × condition interaction was significant (two-factor ANOVA, $F = 5.46$, $p = .0243$). Thus, lengthening appears to improve consonant order judgments in phonologically dyslexic children. Consonant brevity does indeed account for their poor order judgment scores.

Correlations with phonological processes. Rank correlations were performed between the rate of correct responses on each condition explored in the TOJ experiment and each of the four above-reported tasks. Of those, only phoneme deletion and nonword spelling to dictation were found correlated to TOJ performance (first phoneme deletion/normal CCV order judgment, $r = .644$, $p = 0.0175$; simple and complex nonword spelling/temporally modified CCV, $r = .564$, $p = .0448$.

Discussion

The main result of the present study is that dyslexics improve their performance in order judgment when the duration of the two stimuli, but not the spacing between them, is temporally extended. In other words, perceiving the immediate succession of two consonants is more difficult to them than perceiving two consecutive syllables. Moreover, correlations between these order judgment performances and phonological skills strongly suggest that both processes are functionally linked.

The initial finding of impaired performance in judging the order of two consonants is a confirmation of the previous suggestion that dyslexics are specifically impaired in tasks requiring temporal processing and may be taken, per se, as an argument in favor of the temporal deficit theory of dyslexia. However, a causal relation cannot be deduced from this preliminary result, because syllabic complexity may have been the cause of the poor TOJ performance, not event brevity.

The second experiment provides evidence of deficient consonant order judgments in dyslexics, regardless of syllabic structure, because their scores were lower than those of the controls both when the two consonants occurred consecutively in the syllabic onset and when they were separated by a vowel. The difference cannot be ascribed to stimulus duration, since the overall duration was the same. Syllabic complexity therefore does not account for the order judgment deficit.

For the third experiment, in order to demonstrate the link between the duration of events and the judgment of their order, the consonants were artificially lengthened. The results support the contention that short consonants indeed pose a problem for dyslexics, therefore lending strong support to the temporal deficit theory. It is conceivable that these two different aspects of temporal processing—brevity of two events and order of these events—have common neurobiological underpinnings. Further testing of this hypothesis by means of electrophysiological or brain imaging investigation should shed considerable light on the brain mechanisms of this temporal deficit. In addition, other aspects of cognitive impairment, possibly involving time coding, often displayed by dyslexic children, such as awareness of duration or judgment of remoteness, may also be usefully explored in future studies. Finally, such simple tasks may be used in clinical practice as a diagnostic tool and/or as a predictive test for ‘‘auditory temporal training’’ methods currently proposed in the treatment of these children (Tallal et al., 1996; Merzenich et al., 1996; Habib et al., 1999).

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Children with Spina Bifida Perceive Visual Illusions but Not Multistable Figures

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We compared 32 children with spina bifida and 32 age-matched controls on two classes of illusory perception, one involving visual illusions and the other, multistable figures. Children with spina bifida were as adept as age peers in the perception of visual illusions concerned with size, length, and area, but were impaired in the perception of multistable figures that involved figure-ground reversals, illusory contours, perspective reversing, and paradoxical figures. That children with spina bifida reliably perceive illusions that rely on inappropriate constancy scaling of size, length, and area suggests that their brain dysmorphologies do not prevent the acquisition of basic perceptual operations that enhance the local coherence of object perception. That they do not perceive multistable figures suggests that their visual perception impairments may involve not object processing so much as poor top-down control from higher association areas to representations in the visual cortex.

Introduction

Visual Perception in Children with Spina Bifida

Spina bifida meningomyelocele, the most common neural tube defect compatible with survival, occurs at a rate of 0.5–1.0 per 1.000 live births in North America and is characterized by abnormalities of both spine and brain (Fletcher, Dennis, & Northrup, 1999). The spinal dysraphism involves protrusion of the spinal cord and meninges through a defect in the spine at any point along the spinal column. Nearly all children with spina bifida have the Arnold-Chiari II malformation, which involves herniation of a compressed cerebellum through the exits of the fourth ventricle, often causing hydrocephalus and obstruction to the flow of the cerebrospinal fluid in the third and fourth ventricles (Reigel & Rotenstein, 1994).

Children with spina bifida and hydrocephalus have problems with eye movements and with upper limb function, and they perform poorly on tasks of visual perception that have varying demands on the oculomotor and eye–hand control systems (e.g., judgment of line orientation, handwriting). These functional deficits are not surprising in light of the brain dysmorphologies of spina bifida, which involve the cerebellum, midbrain, tectum, and corpus callosum (Barkovich, 1995). Regional variations in brain tissue composition are common in spina bifida, such that the posterior brain regions are more compromised than are anterior regions, and this anterior–posterior asymmetry is related to problems in nonverbal cognition (Dennis et al., 1981), as well as to deficits in more specific visual perception tasks (Fletcher, McCauley, Brandt, Bohan, Kramer, Francis, Thorstad, & Brookshire, 1996).

Illusory Visual Perception

Illusory perception involves a discrepancy between a physical state of affairs and a participant's perception (Day, 1984). Two categories of illusory perception have been studied. *Visual illusions* involve distortions of features such as size, area, and length. While there is still discussion about interpretation of individual illusions and the taxonomy of illusions (Gordon & Earle, 1992, Wenderoth, 1992), there is some agreement that visual illusions arise because of some form of inappropriate constancy scaling (Gregory, 1997). *Multistable figures* are visual phenomena that involve repetitive, subjective changes which continue as long as the pattern is present (Leopold & Logothetis, 1999). Multistable figures reveal top-down effects in perception, because the percepts change while the stimulus remains constant (Gregory, 1997).

Less is known about the brain mechanisms underlying visual illusions than about the neural processing of multistable figures. Recent work implicates the inferior temporal regions in the conscious perception of objects. Earlier accounts of multistable phenomena proposed that perceptual reversals were derived from the autonomous oscillations of a neural circuit within the visual area (e.g., Attneave, 1971; Blake, 1989). More recently, it has been shown that changing stimuli activate the parietal and prefrontal regions, and it has been proposed that multistability is a function of the modification of activity in the visual area by association areas, specifically, that perception of multiple stable states involves a top-down feedback system from frontal–parietal areas to visual areas (Leopold & Logothetis, 1999; Logothetis, 1999; Lumer & Rees, 1999; Sheinberg & Logothetis, 1997).

Specific Aims

Illusory perception provides a tool for addressing two questions about visual perception and visuomotor control in children with spina bifida. The fact that illusion tasks require perception rather than visuomotor control addresses the issue of the extent to which these children are impaired on motor-free visual perception tasks. The fact that one class of illusions is concerned with object processing, and the other with top-down modulation of perception, addresses the nature of visual perception impairment in children with spina bifida. In this study, we compared children with spina bifida and control children on two classes of visual illusions and explored the relation between age, intelligence, and test performance.

Our first aim was to compare children with spina bifida and controls on two classes of illusory perception, one concerned with visual illusions of size, length, and area and the other concerned with multistable figures. The literature suggests that object perception is relatively intact in children with spina bifida and also that multistable perception originates in association areas that act upon representations in the visual cortex. Therefore, we hypothesized that the spina bifida group would perform as well as controls on visual illusions but more poorly than controls on multistable figures.

Our second aim was to relate visual illusions to age and intelligence. Because visual illusions involve constancy scaling related to object processing, whereas multistable figures activate brain regions concerned with higher cognitive functions, we hypothesized that visual illusions would be independent of age and intelligence but multistable figures would be related to both age and intelligence.

Method

Participants

Participants were 32 children diagnosed with spina bifida at birth and treated shortly thereafter with a diversionary shunt to control hydrocephalus. The mean age of the spina bifida group was 11.5 years (SD 2.6; range 6.08–15.92 years). The spina bifida group had a verbal IQ of 94.8 (SD 14.8), a performance IQ of 90.6 (SD 18.4), and a full-scale IQ of 91.0 (SD 15.1). The control group was 32 children from the same educational system as the spina bifida group, selected by teachers to have average classroom performance in language arts and reading. The mean age of the control group was 11.3 years (SD 2.6; range 6.08–15.42 years).

Tasks

The stimuli were 20 visual illusions and multistable figures. The stimuli were presented on 8 × 10-in. cards, with unlimited exposure time.

Visual attribute illusions. These required the participant to perceive illusory distortions of size, area, and length. The top row in Fig. 1 shows examples of the visual illusions. In the Müller–Lyer illusion, the two shafts are equal in length but the lower one appears shorter; participants were asked to indicate whether the two horizontal lines appeared the same or different lengths.

Multistable figures. These required participants to perceive multiple perceptions. The bottom row in Fig. 1 shows examples of the multistable figures, which included figure-ground reversing stimuli, fictions (illusory contours or surfaces), perspective reversing figures (‘‘magic’’ staircase), and paradoxical (impossible) figures. In the figure-ground reversing stimulus, the two animal heads are perceived to alternate with a telephone; the participants were asked to say what they saw and then to say if they saw anything else.

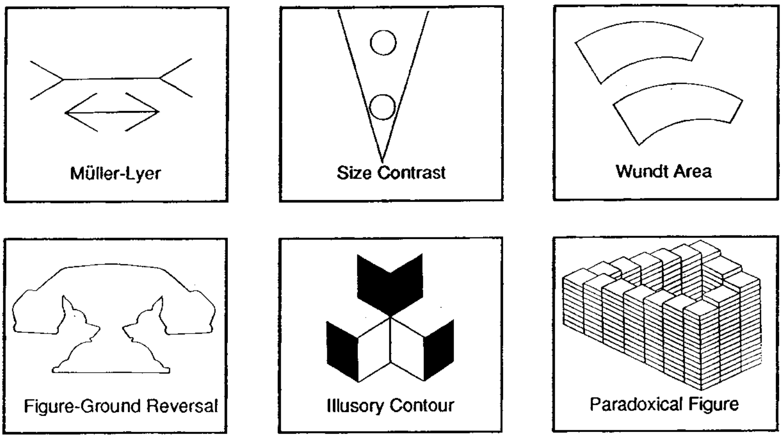

FIG. 1. Example of visual illusions (top row) and multistable figures (bottom row).

Results

The results (Fig. 2) show that the spina bifida and control groups did not differ on the visual attribute illusions, but the spina bifida group performed more poorly than controls on the multistable figures ($F(1, 60) = 6.8$, $p = .0117$). The control group performed significantly better than the spina bifida group on four individual illusions, all of which were multistable figures (figure-ground reversal, illusory contours, paradoxical figures). On two visual illusions (Helmholtz size contrast, size curvature), the spina bifida group performed better than the control group. Of the 14 individual illusions on which the groups did not differ statistically, 12 were visual illusions. The pattern of individual illusions supported the group data.

Inspection of the response data for figures in the bottom half of Fig. 2 showed that children with spina bifida identified multistability less often than controls. Figure-ground reversal (i.e., identification of both the telephone and the animal heads) was achieved by 81% of the control group but only 53% of the spina bifida group. Illusory depth contours were perceived by 38% of the control group but only 16% of the spina bifida group; in the latter, examples of correct responses were ''three boxes'' or ''three cubes'' and examples of incorrect responses were ''6 squares'' or ''each piece is a square with lines connecting it''. Impossible depth relations in the paradoxi-

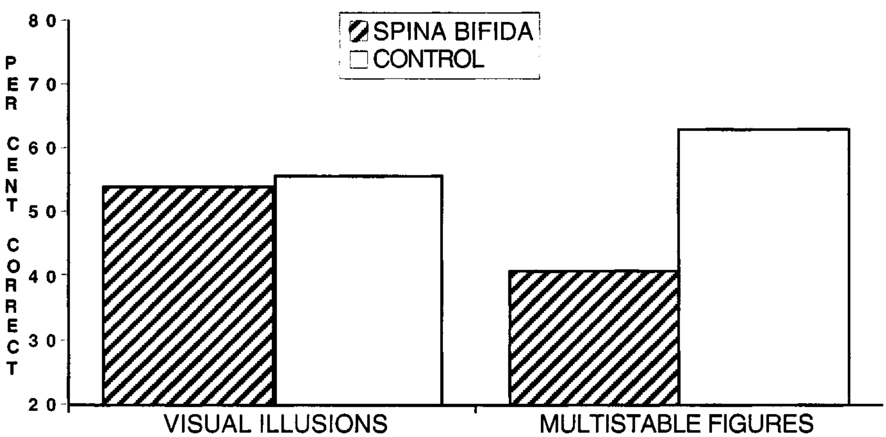

FIG. 2. Performance of spina bifida and control groups on visual illusions and multistable figures.

cal figure were identified by 88% of the control group but only 41% of the spina bifida group; in the latter, examples of correct responses were ‘‘stairs going around and around but weird, not really going one way’’ and examples of incorrect responses were ‘‘looks fine’’ or ‘‘they’re stairs.’’

Multiple regressions of age and IQ on test scores were conducted for the spina bifida group. Visual illusions were unrelated to age, verbal IQ, or performance IQ. Multistable figures were unrelated to verbal IQ, but were significantly improved by both an older age ($t(30) = 5.9$, $p < .0001$) and a higher performance IQ ($t(30) = 2.3$, $p = .0295$).

Discussion

Children with spina bifida are as adept as age peers at perception of visual illusions concerned with size, length, and area (unlike, for example, children with autism, who fail to perceive many of the two-dimensional illusions tested here; Happé, 1996). However, children with spina bifida are impaired in the perception of multistable figures that involve figure-ground reversals, illusory contours, perspective reversing, and paradoxical figures. The impairment of children with spina bifida on multistable figures is consistent with data suggesting that object perception in these children is more intact than is the perception of figure-ground relationships (Fletcher, Brookshire, Bohan, Brandt, & Davidson, 1995).

That children with spina bifida reliably perceive illusions that rely on inappropriate constancy scaling of size, length, and area suggests that their brain dysmorphologies do not prevent the acquisition of basic perceptual operations that enhance the local coherence of object perception. That they do not perceive multistable figures suggests that their visual perception impairments involve not object processing so much as poor top-down control from higher association areas to representations in the visual cortex. Age improved the perception of multistable figures, which suggests that the control of visual cortex by higher, association areas may improve with development.

While visual illusions concern perceptual processes, it may be that the top-down control required for multistability in perception overlaps with the system controlling perception for action (Milner & Goodale, 1996), in accordance with recent theories proposing that processing of multistable figures is part of a more general-purpose mechanism that also mediates exploratory eye movements and the control of attention (Leopold & Logothetis, 1999). Multistability in perception is related to intelligence in adulthood (Crain, 1961), and here, performance IQ (several subtests of which require visual motor control) was correlated with multistable figures, but not with visual illusions. This suggests a more general relation between the perception of multistable figures and visual perception tasks that require action systems.

For the spina bifida group, the difficulty in perception of multistable figures needs further exploration in terms of clinical correlates, processing characteristics, and neuropathological substrate. Ophthalmological information is needed to understand whether poor stereopsis in this population, which arises by virtue of eye movement disorders, contributes to a failure in binocular fusion and produces inability to perceive visual illusions that depend on depth. Studies of spina bifida using multistable figures with well-identified perceptual properties (e.g., binocular rivalry) would be useful in clarifying the nature of the impairment in the spina bifida group. Neuroimaging in children with spina bifida may provide clues about the brain areas involved in various levels of visual processing, such as the brain stem neural network that controls eye position (Seung, 1998). Also, the consequences of posterior cortical thinning need to be explored; it may be that the thinned posterior association cortex in children with spina bifida will not support the top-down feedback required for perception of multistable figures.

The illusory perception of children with spina bifida seems not unlike their language comprehension. In the language domain, these children succeed in making comparative judgments and attaining local coherence, but fail to understand ambiguous or literally implausible, figurative linguistic constructions and do not reliably use biasing contexts to achieve a top-down control of ongoing language comprehension (Dennis & Barnes, 1993; Barnes & Faulkner, 1999).

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Adult Attention-Deficit/Hyperactivity Disorder: Neuropsychological Correlates and Clinical Presentation

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We compared the neuropsychological test performance of adult ADHD patients to the neurocognitive profiles of control subjects recruited from the general population. We administered a neuropsychological test battery consisting of measures considered sensitive to either orbitofrontal or dorsolateral–prefrontal (DLPF) dysfunction. Orbitofrontal hypoarousal is associated with behavioral disinhibition and a relative indifference to punishment. The DLPF region may function as a central executive system. Indeed, DLPF dysfunction may underlie many of the cardinal symptoms associated with ADHD. We tested the following hypotheses: (1) adult subjects meeting *DSM-IV* criteria for ADHD, predominantly hyperactive–impulsive type, would display neuropsychological deficits on tasks sensitive to orbitofrontal dysfunction; (2) adult subjects meeting *DSM-IV* criteria for ADHD, predominantly inattentive type, would perform poorly on measures sensitive to DLPF dysfunction; and (3) adult subjects meeting *DSM-IV* criteria for ADHD, combined type, would exhibit performance deficits on orbitofrontal measures and on DLPF tasks. Results partially confirmed our hypotheses. Subtyping ADHD patients revealed important group differences. Distinct neurocognitive and clinical profiles were observed.

Introduction

Attention-deficit/hyperactivity disorder (ADHD) is a common developmental disorder affecting between 3 and 5% of school-age children (American Psychiatric Association, 1994). In recent years, researchers have suggested that clinically significant symptoms persist into adulthood (Biederman, 1991) and clinicians are, increasingly, making an initial ADHD diagnosis during the adult years. In addition, adult ADHD is associated with a broad spectrum of comorbid psychiatric conditions including Axis-II disorders (e.g., antisocial personality disorder), substance abuse, and anxiety and mood disorders (Biederman, 1991; Downey et al., 1997; Shekim et al., 1990). However, research exploring the neuropsychological function of adults presenting with ADHD is limited. Previous studies have shown that adults with ADHD, in comparison to control subjects, exhibit greater neuropsychological deficits on tasks considered sensitive to frontal lobe dysfunction (Downey et al., 1997; Kovner et al., 1998; Lovejoy et al., 1999).

Converging lines of evidence suggest that dorsolateral prefrontal cortex (DLPF) mediates executive functions, while orbitofrontal cortex (OFC) modulates emotional arousal and sensitivity to reinforcement contingencies. Orbitofrontal *hypo*arousal is associated with behavioral disinhibition and a relative indifference to punishment. Cummings (1993) described a disinhibition syndrome associated with orbitofrontal damage. Numerous case studies document the emergence of impulsive, antisocial behavior following orbitofrontal lesions (Blumer & Benson, 1975; Meyers, Berman, Scheibel, & Hayman, 1992).

In this study, we compared the neuropsychological test performance of adult ADHD patients to the neurocognitive profiles of control subjects recruited from the general population. We administered a neuropsychological test battery consisting of measures considered sensitive to either orbitofrontal or dorsolateral–prefrontal (DLPF) dysfunction.

We tested the following hypotheses:

1. Adult subjects meeting *DSM-IV* criteria for ADHD, predominantly hyperactive–impulsive type, would display neuropsychological deficits on tasks considered sensitive to orbitofrontal dysfunction (e.g., the object alternation test);
2. Adult subjects meeting *DSM-IV* criteria for ADHD, predominantly inattentive

type, would perform poorly on measures sensitive to DLPF dysfunction (i.e., tests assessing frontal executive functioning). Indeed, DLPF dysfunction may underlie many of the cardinal symptoms associated with ADHD including attentional difficulties, poor planning, and difficulty anticipating consequences;
3. Adult subjects meeting *DSM-IV* criteria for ADHD, combined type, would exhibit performance deficits on orbitofrontal measures and on DLPF tasks.

Method

Thirty individuals responded to a newspaper advertisement seeking adults diagnosed with ADHD. In addition to the clinical diagnosis, we required that subjects exceed recommended symptom thresholds on the current symptoms scale (CSS), based on *DSM-IV* criteria (Barkley & Murphy, 1998). Five subjects failed to exceed cutoff scores on the CSS and were excluded from statistical analysis.

The complete ADHD sample consisted of 9 males and 16 females between the ages of 19 and 66 years ($M = 35.6$, $SD = 15.9$). The mean education level was 15.0 years ($SD = 1.7$). Twenty-one ADHD subjects were right-handed and four subjects were left-handed, as determined by self-report. Control subjects ($n = 11$) were recruited from the general population. There were 5 males and 6 females between the ages of 21 and 47 years ($M = 35.4$, $SD = 9.9$). The mean educational level of the control group was 16.1 years ($SD = 2.3$). Ten control subjects were right-handed and one subject was left-handed, as determined by self-report. Written informed consent was obtained from all subjects and all participants received financial compensation ($25).

We administered a battery of measures sensitive to frontal lobe dysfunction to ADHD subjects and community controls. The battery included computer versions of the object alternation test (OAT) (Freedman, 1990), Stroop Color-Word Test, and a Go/No-Go task (based on Lapierre et al., 1995) (putative orbitofrontal measures).

We also administered tests of frontal executive functioning (i.e., measures considered sensitive to DLPF dysfunction) including the Controlled Word Fluency Test (FAS Test) (Goodglass & Kaplan, 1972) and a divergent thinking task (Lezak, 1995). An examination of the relationship between neuropsychological test performance and clinical presentation (i.e., *DSM-IV* subtypes) was our principal research goal. Since we were also interested in examining patterns of psychiatric comorbidity, we administered a battery of personality questionnaires and clinical scales. Administered tests included:

—Cattell's 16 Personality Factor Questionnaire (16PF) (Factors G, H, and O) (Cattell, 1989);
—Personality Diagnostic Questionnaire (PDQ-4) (Hyler, 1994):
  Antisocial Personality Disorder (APD) Subscale and
  Obsessive-Compulsive Personality Disorder (OCPD) Subscale;
—Fear Survey Schedule (Wolpe & Lang, 1964) (a modified version consisting of four subscales):
  Agoraphobia Subscale,
  Claustrophobia Subscale,
  Specific Phobic Situations Subscale, and
  Social Phobia Subscale;
—Frontal Lobe Personality Scale–Patient Version (Grace & Malloy, 1992); and
—Current Symptoms Scale (CSS) (Barkley & Murphy, 1998).

The Frontal Lobe Personality Scale (Grace & Malloy, 1992) requires subjects to indicate how frequently they experience symptoms or exhibit behaviors associated with frontal lobe dysfunction including behavioral disinhibition, executive function deficits, and apathy, reflecting orbitofrontal, DLPF, and mesial/anterior cingulate dysfunction, respectively.

The CSS (Barkley & Murphy, 1998) yields three scores reflecting *DSM-IV* criteria for: (1) ADHD, predominantly hyperactive–impulsive type; (2) ADHD, predominantly inattentive type; and (3) ADHD, combined type.

We chose three subscales from the 16PF Questionnaire (Factors G, H, and O) which we anticipated would most accurately reflect personality characteristics associated with ADHD (see Table 1). Since adult ADHD patients frequently present with comorbid conditions, particularly anxiety states and APD, we administered the Fear Survey Schedule and the PDQ-4 (APD and OCPD subscales). The inclusion of the latter subscale is based on our finding, in a separate study, that performance deficits on measures sensitive to DLPF dysfunction correlated with OCPD subscale scores (Dinn, Harris, & Andover, 1999). We suggested that the preoccupation with rules and organization, perfectionism, and inflexibility displayed by OCPD subjects may represent behavioral strategies which evolve in response to executive function deficits (i.e., DLPF dysfunction).

The protocol was long, averaging 2 h for control subjects. Time to completion was highly variable across ADHD subjects. In some cases the experimental session had to be concluded early due to subject fatigue; in other cases subjects asked to end specific tasks before they were completed. For these reasons not all tasks were run on all ADHD subjects. In our analyses, degrees of freedom in the t statistics vary according to how many subjects participated in that task. Note that we did not administer the Frontal Lobe Personality Scale to the 11 control subjects described above. We incorporated the scale into our battery after we had completed testing of controls. Therefore, we will compare Frontal Lobe Personality Scale scores of ADHD subjects to a separate control group ($n = 18$) consisting of 10 males and 8 females recruited from the community. Groups did not reveal significant differences in age or educational level (ps $> .20$).

Results

Subtype analysis. We employed the CSS to determine subtype classification. Four subjects met *DSM-IV* criteria for ADHD, predominantly hyperactive–impulsive

TABLE 1
16 PF Subscales

Low score	High score
Factor G	
Expedient	Conscientious
Disregards rules, self-indulgent	Persistent, Moralistic, Staid
Factor H	
Shy	Bold
Threat-sensitive, hesitant, intimidated	Venturesome, Uninhibited
Factor O	
Untroubled adequacy	Guilt proneness
Self-assured, placid, secure, complacent	Apprehensive, Self-reproaching, Insecure, Worrying, Troubled

Note. From Cattell, H. B. (1989). *The 16PF: Personality in depth.* Champaign, IL: IPAT.

type. Eight subjects met *DSM-IV* criteria for ADHD, predominantly inattentive type. Thirteen subjects met *DSM-IV* criteria for ADHD, combined type.

ADHD, predominantly hyperactive–impulsive type. Subjects with ADHD, predominantly hyperactive–impulsive type showed performance impairments on the object alternation test in comparison to community controls ($t(13) = 6.404$, $p < .001$). No group differences were obtained on the Stroop (all *p*s $> .15$) and Go/No-Go tasks (all *p*s $> .50$), and divergent thinking task ($p > .90$).ADHD (hyperactive–impulsive subtype) subjects generated fewer words during the verbal fluency task (nonsignificant trend, $p < .10$). ADHD (hyperactive–impulsive subtype) subjects achieved higher scores on the disinhibition subscale (nonsignificant trend, $p < .08$), while no group differences were observed on subscales assessing executive dysfunction ($p > .70$) and apathy ($p > .20$).

ADHD subjects obtained significantly higher scores on Factor O ($t(13) = 2.309$, $p < .04$) and displayed higher scores on the APD subscale (nonsignificant trend) ($p < .07$) relative to community controls. However, no group differences were obtained on the remaining personality factors (all *p*s $> .30$) and clinical scales including all Fear Survey Subscales (all *p*s $> .45$).

ADHD, predominantly inattentive type. Subjects presenting with ADHD, predominantly inattentive type, did not display performance deficits on the object alternation test ($p > .65$) and Stroop task (all *p*s $> .19$) (putative orbitofrontal measures), while they showed performance impairments during all three blocks of the Go/No-Go task ($t(17) = 3.084$, $p < .007$; $t(17) = 3.465$, $p < .003$; $t(17) = 2.438$, $p < .03$) and tests of executive function (i.e., word fluency($t(17) = -3.381$, $p < .004$) and divergent thinking ($t(17) = -2.303$, $p < .04$) tasks). In addition, participants with ADHD, inattentive subtype, attained significantly higher scores on the executive dysfunction subscale of the Frontal Lobe Personality Scale ($t(24) = 3.430$, $p < .002$), while no group differences were observed on subscales reflecting orbitofrontal ($p > .75$) or mesial/anteriorcingulate ($p > .40$) dysfunction.

ADHD subjects also scored significantly higher on Factor O ($t(17) = 3.851$, $p < .001$), agoraphobia ($t(17) = 2.540$, $p < .03$), claustrophobia ($t(17) = 2.781$, $p < .02$), and social phobia ($t(17) = 2.686$, $p < .02$) subscales of the Fear Survey Schedule and on the OCPD subscale ($t(17) = 2.501$, $p <.03$). They did not differ from control subjects on the APD subscale ($p >.75$) and Factors G and H from the 16PF (*p*s $> .35$).

ADHD, combined type. Subjects meeting *DSM-IV* criteria for ADHD, combined type, exhibited performance deficits on the conflict blocks of the Stroop ($p < .08$) and Go/No Go ($p < .10$) tasks (nonsignificant trends) and generated significantly fewer words during the word fluency task ($t(21) = -2.455$, $p < .03$). Moreover, ADHD subjects exhibited slower reaction times in comparison to community controls during the first block of the Go/No-Go task ($t(21) = 2.479$, $p < .03$). ADHD subjects scored significantly higher on subscales of the Frontal Lobe Personality Scale assessing disinhibition ($t(29) = 4.185$, $p < .001$) and executive function deficits ($t(29) = 3.663$, $p < .001$), while group differences were not observed on the apathy subscale ($p > .20$). No group difference were observed on the object alternation test ($p > .60$) and divergent thinking task ($p > .80$).

ADHD subjects scored significantly higher on the social phobia subscale ($t(22) = 2.102$, $p < .05$) and OCPD ($t(21) = 3.772$, $p < .001$) and APD($t(21) = 2.924$, $p < .008$) subscales. Group differences were not observed for the remaining personality factors (all *p*s $> .15$) and clinical scales (all *p*s $> .13$).

Medication effects. Almost half (46%) of the ADHD subjects were undergoing pharmacotherapy (primarily stimulants) at the time of testing. To address the issue of medication effects on neuropsychological test performance, we compared the neurocognitive profiles of medicated and unmedicated ADHD participants. None of the control subjects were taking psychoactive medications. The clinical and neurocognitive profiles of medicated and unmedicated ADHD subjects were remarkably similar. Groups did not differ significantly on the object alternation test ($p > .90$), Stroop task (all *p*s $> .24$),Go/No-Go task (all *p*s $> .85$), divergent thinking task ($p > .35$), and all three subscales of the Frontal Lobe Personality Scale (all *p*s $> .70$). However, medicated subjects generated significantly fewer words during the verbal fluency task ($p < .02$).

Discussion

Subtyping ADHD patients revealed important group differences. Distinct neurocognitive and clinical profiles were observed. The neurocognitive performance patterns of the three ADHD subgroups may reflect abnormalities in functionally and anatomically distinct subdivisions of the prefrontal region.

ADHD, predominantly hyperactive–impulsive type. As expected, subjects with ADHD, hyperactive–impulsive type, displayed significant impairment on the object alternation test, a neuropsychological task considered sensitive to orbitofrontal dysfunction (Freedman, 1990; Freedman, Black, Ebert, & Binns, 1998; Mishkin, 1964; Mishkin, Vest, Waxler, & Rosvold, 1969; Pribram & Mishkin, 1956). However, ADHD (hyperactive–impulsive type) subjects did not perform in the expected manner on all tasks. For example, we had assumed that the conflict blocks of the Stroop and Go/No-Go tasks would also index orbitofrontal dysfunction, yet no deficits were observed among subjects presenting with ADHD, hyperactive–impulsive subtype.

Our hypothesis was that the hyperactive–impulsive subtype would show deficits on tasks considered sensitive to orbitofrontal dysfunction. This hypothesis was partially confirmed via the finding of greater number of trials, relative to controls, to solve the object alternation test. In prior work, the object alternation test has been a robust marker of orbitofrontal dysfunction. Indeed, only the hyperactive–impulsive subtype showed deficits on the task. Relative to controls, ADHD subjects reported an increased incidence of antisocial behavior, which is consistent with the proposal that underarousal of orbitofrontal cortex mediates disorders of disinhibition and impulse control. As anticipated, ADHD (hyperactive–impulsive type) and community control subjects did not demonstrate significant group differences on tests of executive function.

Scores on the Frontal Lobe Personality Scale are consistent with neuropsychological test results. Subjects presenting with ADHD (hyperactive–impulsive subtype) scored higher on the disinhibition subscale (possibly reflecting orbitofrontal dysfunction). However, ADHD (hyperactive–impulsive type) and control group differences on the executive dysfunction and apathy subscales were not statistically significant.

The scores of ADHD subjects (hyperactive–impulsive subtype) on all Fear Survey subscales, OCPD subscale (PDQ-4+), and Factors H and G (16PF) did *not* differ significantly from the scores achieved by control participants. However, ADHD subjects achieved higher scores on Factor O and on the APD subscale (nonsignificant trend). The latter finding is consistent with prior studies reporting elevated rates of antisocial behavior among adults presenting with ADHD.

ADHD, predominantly inattentive type. As expected, subjects presenting with ADHD, predominantly inattentive type, demonstrated impairment on tests of executive function and they did *not* exhibit performance deficits on tasks considered sensitive to orbitofrontal dysfunction (i.e., the OAT and Stroop task). ADHD subjects (inattentive type) exhibited performance deficits during the Go/No-Go task in comparison to community controls.

We anticipated that ADHD subjects (inattentive subtype) would perform poorly on executive function tasks, while they would *not* demonstrate greater neuropsychological deficits on tasks sensitive to orbitofrontal dysfunction. The latter hypothesis was confirmed in that these subjects were not impaired on the object alternation test. If the Go/No-Go task can be considered an executive function task, then the first of these hypotheses was also confirmed, since we found deficits on all three blocks of the Go/No-Go task, and also deficits on classic executive function tasks (e.g., the verbal fluency and divergent thinking tasks). The Go/No-Go task may specifically tap ADHD symptoms, given that it is largely a vigilance task (i.e., the subject must prepare a motor response to fit into a short (750 ms) response window).

Deficits in performance during the Go/No-Go task (e.g., a false alarm) appear to reflect a failure in impulse control (which presumably reflects orbitofrontal dysfunction). However, executive functions such asset shifting are subserved by the DLPF system. During the Go/No-Go task subjects are required to shift response set. The Go/No-Go task required subjects to press the space bar as quickly as possible when a blue square appears (against a white background). During the first block (50 trials) only blue squares are displayed. During the second block (50 trials) subjects were instructed to respond when the blue square appears and refrain from responding when a blue cross is displayed. During the third block (50 trials) subjects must shift response set. They are instructed to respond when the blue cross is displayed and refrain from responding when the square appears. The blue square or blue cross appears at random locations across the computer screen. The interstimulus interval was also randomized with intervals of 100, 250, 400, 500, 750, 1000, or 2000 ms. Although performance deficits (e.g., reaction time slowing and frequency of false alarms) on Go/No-Go tasks are associated with orbitofrontal lesions, functional neuroimaging studies document neuroactivation patterns involving both orbitofrontal and DLPF regions. During the first block of the Go/No-Go task the subject must prepare a motor response to fit into a short (750 ms) response window. Efficient performance requires sustained attention and motor control. Thus, the Go/No-Go task should be considered a broadly frontal task.

Impaired verbal fluency may reflect DLPF dysfunction. Regional cerebral blood flow (rCBF) and PET studies revealed significant flow augmentation and increased activity in dorsolateral–prefrontal cortex during verbal fluency tasks.

Frontal Lobe Personality Scale scores were consistent with the neurocognitive profile displayed by ADHD subjects (inattentive subtype). They scored significantly higher on the executive dysfunction subscale, while they did not differ from control subjects on the disinhibition or apathy subscales.

ADHD subjects (inattentive subtype) demonstrated elevated scores on three Fear Survey Schedule subscales, OCPD subscale, and Factor O, relative to control participants. This clinical profile is consistent with prior studies reporting high rates of anxiety disorders among adults presenting with ADHD. There was no significant difference between groups on the APD subscale.

ADHD, combined type. We had anticipated that the combined type would show performance deficits on tasks sensitive to orbitofrontal and DLPF dysfunction. This was not completely borne out, since they did not display deficits on the object alternation test. However, there were trends for poorer performance, relative to controls, on the Stroop and Go/No-Go tasks. Subjects presenting with ADHD, combined type, displayed performance deficits on the Stroop and Go/No-Go tasks (nonsignificant trends) and demonstrated impaired word generation in comparison to community controls. ADHD subjects also achieved significantly greater scores on subscales reflecting orbitofrontal *and* DLPF dysfunction and scored significantly higher on the social phobia, APD, and OCPD subscales. The latter finding is particularly intriguing.

In a prior study, we found that performance deficits on measures sensitive to DLPF dysfunction correlated strongly with OCPD subscale scores (Dinn, Harris, & Andover, 1999). We suggested that the preoccupation with rules and organization, perfectionism, and inflexibility displayed by OCPD subjects may represent behavioral strategies which evolve in response to executive function deficits. In the present study, ADHD subjects (inattentive and combined subtypes) attained clinically significant scores on the OCPD subscale. We found an association between obsessive–compulsive personality traits and executive function deficits among ADHD subjects. This suggests that ADHD patients may also evolve compensatory behavioral strategies (i.e., OC personality traits) in response to DLPF dysfunction.

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Production of Narratives: Picture Sequence Facilitates Organizational but Not Conceptual Processing in Less Educated Subjects

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Fifty-three healthy older adults were produced stories induced by two types of picture stimuli (single picture and picture sequence). Discourse samples were analyzed for: (1) percentage of expected main ideas (which reflect conceptual processing) and (2) number of transitional markers (which reflect organizational processing). Results indicate that the older group (75 to 84 years) produced a lower percentage of main ideas and less transitional markers than the younger group (65 to 74 years). Both groups also showed better performance in response to the picture sequence than to the single picture. For the percentage of expected main ideas, however, a superior performance in response to the picture sequence was observed only among older subjects with higher (11 to 18 years) but not lower (4 to 10 years) levels of formal education. The role of education and the importance of stimulus type in discourse-specific tasks are discussed.

Introduction

Efficient story telling necessitates processing on at least three representational levels (Frederiksen, Bracewell, Breuleux, & Renaud, 1989). The story must be organized according to a canonical narrative structure, it must contain conceptual information specific to the story, and it must be told within the confines of language (respecting the rules of syntax and grammar). Evidence from the discourse literature points to age-related impairments on both organizational (Gloser & Deser, 1992) and conceptual (Ehrlich, Obler, & Clark, 1997; Laliberté, 1993) levels, while the linguistic level appears relatively well preserved (Gloser & Deser, 1992). Further, education is thought to confer an advantage to older subjects on a wide range of verbal and nonverbal cognitive tasks (Evans, Beckett, Albert, Hebert, Scherr, Funkenstein, & Taylor, 1993; Lyketsos, Chen, & Anthony, 1999). Finally, picture stimulus type (single picture and picture sequence) may necessitate differing levels of cognitive demand. With respect to narrative discourse, picture sequences may facilitate higher-level processing because multiple individual pictures are presented thus helping to organize conceptual information. When only a single picture is presented, subjects not only have to extract the conceptual information, but also must organize this information within a narrative structure.

The purpose of this study is to describe discourse production induced by either a single picture or a picture sequence in older subjects with higher versus lower levels of formal education. Given that age-related impairments have been observed in discourse processing and that education is thought to play a protective role on a wide range of cognitive tasks, it is reasonable to expect that education might contribute to the preservation of discourse-specific cognitive skills in aging. It was also hypothesized that a picture sequence would induce more complete narrative discourse than a single picture in older subjects, although it was difficult to predict how stimulus type would interact with increasing age and varying levels of education.

Methods

Subjects. Fifty-three older adults with no history of neurological, psychiatric, or medical abnormality took part in this study. They were divided into four groups according to two levels of age (65 to 74 and 75 to 84 years) and two levels of formal education (4 to 10 and 11 to 18 years). The four groups were younger with higher education (YH), younger with lower education (YL), older with higher education (OH), and older with lower education (OL).

Tasks. Each subject was asked to produce two stories, one induced by the presentation of a single picture depicting a bank robbery (Lecours, Rascol, Nespoulous, Joanette, & Puel, 1986) and the other, by the presentation of seven pictures depicting a car accident (Joanette, Ska, Poissant, Belleville, Lecours, & Peretz, 1995). These seven pictures were laid out in sequential (and temporal) order according to the story line. To eliminate any memory-specific effect, both the single picture and the full picture sequence were left uncovered for the duration of the session. Instructions given to subjects were ''Look at this (these) picture(s) and tell me the story that you see.'' Productions were time unlimited and sessions were terminated by the experimenter when no new information was produced despite further prompting.

Dependent variables and statistical analyses. Discourse samples were transcribed and analyzed to obtain: (1) percentage of expected main ideas (reflecting the conceptual information contained in each narrative) and (2) number of temporal and sequential transitional markers (reflecting organizational ability according to the narrative structure proposed by Kintsch and van Dijk (1978)). Three-factor analyses of variance were performed on each measure to determine the effects of age, education, and stimulus type.

Results

Results obtained on percentage of expected main ideas reveal a main effect of age ($F_{1,49} = 10.61$, $p = .0020$) indicating that younger subjects produced a higher percentage of expected main ideas (average = 56.25%; SD = 1.52%) than older subjects (average = 47.85%; SD = 0.83%). Results also indicate an interaction between stimulus type and education ($F_{1,49} = 7.63$; $p = .0080$). A decomposition of this effect indicates that the differences in performance observed across stimulus type are accounted for by the high education groups ($F_{1,49} = 10.69$; $p = .0020$) who produced a higher percentage of expected main ideas in response to the picture sequence (average = 57.42%; SD = 1.52%) than to the single picture (average = 48.23%; SD = 1.92%). No statistically significant differences were observed between the low education groups ($F_{1,49} = 0.40$, $p = .5229$). The percentage of expected main ideas produced by all four groups is depicted in Fig. 1.

Results obtained on the number of transitional markers indicate main effects of stimulus ($F_{1,49} = 53.07$, $p < .0001$) and age ($F_{1,49} = 5.40$, $p = .0244$). All subjects produced more transitional markers in response to the picture sequence (average = 3.53, SD = 0.20) than to the single picture (average = 1.92, SD = 0.14), and younger subjects produced more transitional markers (average = 2.98, SD = 0.19) than older subjects (average = 2.39, SD = 0.22). No main effect of education and no interaction

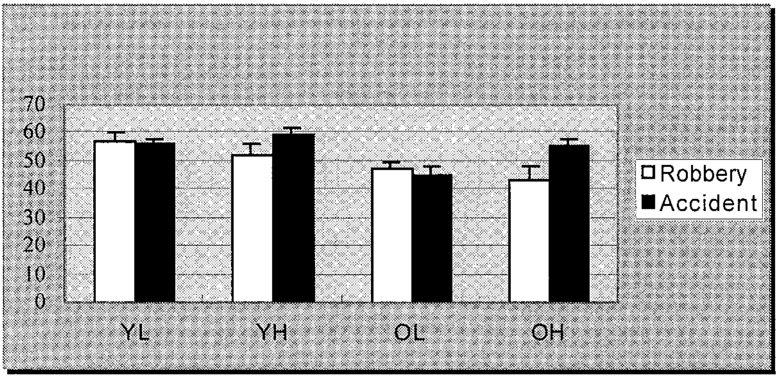

FIG. 1. Percentage of expected main ideas. YL (younger and lower education); YH (younger and higher education); OL (older and higher education); OH (older and higher education).

effects were observed on this variable. The total number of logical transitions are depicted in Fig. 2.

Discussion

Results support and replicate earlier studies (Ehrlich, Obler, & Clark, 1997; Gloser & Deser, 1992; Laliberté, 1993) indicating both conceptual and organizational impairment among older subjects. This was evidenced by the production of a higher percentage of expected main ideas and a greater number of transitional markers by the younger groups (YL and YH) compared to the older groups (OL and OH). Results also suggest that, whereas education is considered to play a protective role on tasks which do not directly tap discourse processing, it does not seem to do so on discourse-specific tasks because no interactions between education and age were observed. Finally, results demonstrate that stimulus type can affect discourse performance among older subjects. Indeed, the picture sequence appeared to facilitate discourse performance because all subjects produced a greater number of transitional markers in response to it than in response to the single picture. For the number of main ideas, however, the facilitating effect of the picture sequence was only observed among older subjects with higher, but not with lower, levels of formal education.

The fact that less educated older subjects benefit from the easier task on measures

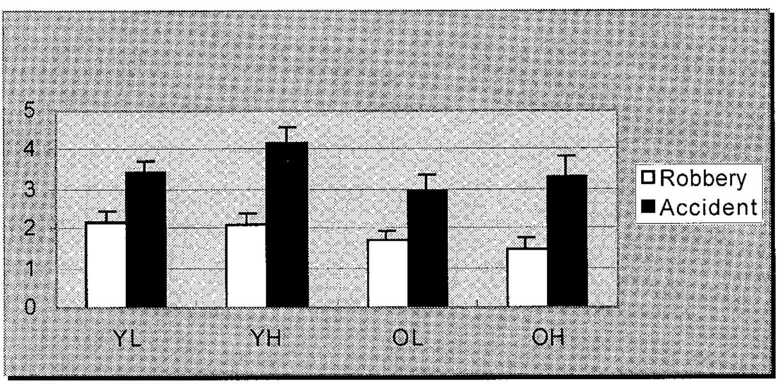

FIG. 2. Number of transitional markers. YL (younger and lower education); YH (younger and higher education); OL (older and higher education); OH (older and higher education).

related to organizational but not conceptual processing is intriguing. It can be argued that formal education confers a richer knowledge of the world which is then reflected in the production of more general ideas in the stimulus situation. At the same time, aging is thought to slow down general cognitive processing (Salthouse, 1996), regardless of education. It is therefore possible that while older subjects with less education preferentially base their discourse production on explicit visual cues (yielding relatively less elaboration of conceptual content), subjects with more education benefit from the same explicit visual cues while maintaining the ability to elaborate on this information.

While these results provide evidence that education can modulate discourse performance at the conceptual level, they do not clarify the mechanisms through which education may act. It is possible that education raises the threshold for age-related cognitive decline (Christensen, Korten, Jorm, Henderson, Jacomb, Rodgers, & Mackinnon, 1997; Leibovici, Ritchie, Ledesert, & Touchon, 1996). Therefore, among older individuals, education is a factor that should be considered in the assessment of tasks that require high levels of cognitive processing, such as the production of narratives.

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Handedness and Depression in University Students: A Sex by Handedness Interaction

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Previous research has indicated that there is an increased incidence of left-handedness in samples of depressed individuals. We administered the Beck Depression Inventory (BDI) to a sample of 541 undergraduate students. Left-handed males showed significant elevation of BDI scores. It is unlikely that this result is due to decreased right hemisphere activity or sex-role conflicts. However, one possibility is that known differences in male steroid hormones levels between right- and left-handers contributed to this effect.

Evidence from clinical and normative populations clearly indicates that the perception of emotion (particularly negative emotion) is usually functionally lateralized to the right hemisphere. Patients suffering right-hemispheric lesions demonstrate impairments in prosodic perception (Heilman, Scholes, & Watson, 1975) and identifying emotional facial expressions (DeKosky, Heilman, Bowers, & Valenstein, 1980). Neurologically normal populations exhibit right hemisphere advantages for perception of prosody (Bulman-Fleming & Bryden, 1994) and emotional facial expressions (Suberi & McKeever, 1977).

Several lines of research suggest that right hemisphere dysfunction is present in patients with emotional disorders, such as depression. For example, depressed patients exhibit deficits on visuospatial tests (Flor-Henry, 1976) and often fail to show the normal left ear (right hemisphere) advantage for dichotic-listening tasks employing musical tones or click stimuli (Bruder, Sutton, Berger-Gross, Quitkin, & Davies, 1981; Johnson & Crockett, 1982).

There is extensive literature documenting the association between left-handedness and various pathologies such as allergies and developmental language disorders (see Bishop, 1990, for a review). Despite this extensive literature, there is no clear consensus regarding the relation between atypical lateralization of function (such as left-handedness) and atypical emotional processing, such as that seen during major depression. Some investigators report an increased prevalence of left-handers among patients suffering from clinical depression or those with higher scores on measures of depression (Biederman, Lapey, Milberger, Faraone, Reed, & Seidman, 1994; Bruder, Quitkin, Stewart, Martin, Voglmaier, & Harrison, 1989; Herzog, 1989; Overby, 1994; Portellano Perez & Robles Sanchez, 1998). However, others have found no evidence for this effect (Clementz, Iacono, & Beiser, 1994; Shan ming et al., 1985). Nonetheless, others find decreased prevalence of left-handedness in depressed samples (Abrams & Taylor, 1987; Merrin, 1984; Moscovitch, Strauss, & Olds, 1981). The relation between handedness and anxiety appears to be somewhat clearer. In college student samples, Hicks and Pellegrini (1978) and Davidson and Schaffer (1983) both found that mixed-handed and left-handed college students scored significantly higher on anxiety tests than did right-handed students.

The present study sought to examine the relationship between handedness, sex, and depression in a subclinical, normal population. It was hypothesized that left-handers would score higher on a measure of depression than right-handers, with female left-handers scoring highest on the measure.

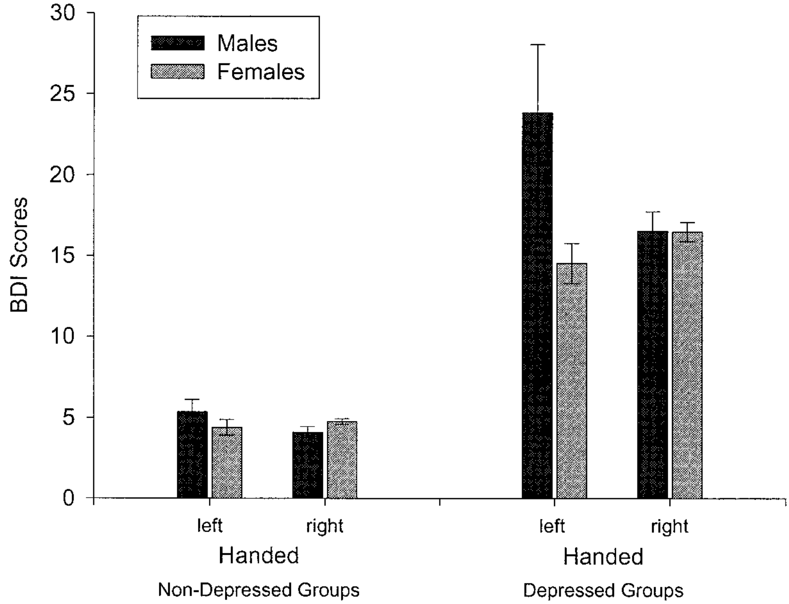

FIG. 1. BDI scores of males and females by handedness and BDI depression cutoff recoding. Values are means ± SEM.

Method

Participants and procedure. As part of a research and screening questionnaire given to all students enrolled in an introductory psychology course, participants completed the Beck Depression Inventory (BDI) (Beck, Ward, Mendelson, Mock, & Erbaugh, 1961). In addition to providing data for the present study, these measures served as screening devices for subsequent studies performed by other researchers. Only those individuals providing complete data for the BDI were eligible for inclusion in this study, for a total of 541 undergraduate participants.

On the same questionnaire, participants indicated their sex and handedness. As such, 55 participants indicated that they were left-handed (17 men and 38 women). Of the remaining 486 right-handed participants, 100 were men and 386 were women.

Data analysis. Initially, the BDI was scored as per the criteria outlined in Spreen and Strauss (1998), with a maximum score of 63. These BDI scores were then analyzed using analysis of variance (ANOVA) with the between-subjects variables of sex and handedness.

To determine whether the observed effects could be caused by a few individuals with extreme scores, the data was then recoded according to the following scheme: Individuals with scores of 0–9 on the BDI were categorized as 'normal,' and individuals with scores of 10+ (indicative of 'mild' to 'severe' depression according to Spreen & Strauss, 1998) were classified as 'depressed.' For left-handers, this recoding resulted in 11 nondepressed males, 6 depressed males, 25 nondepressed females, and 13 depressed females. For right-handers, this recoding resulted in 69 nondepressed males, 31 depressed males, 250 nondepressed females, and 136 depressed females.

Results

A 2 × 2 ANOVA using sex (M, F) and handedness (right-, left-) as between-subjects measures was performed on the BDI scores. We found a significant hand × sex interaction ($F(1, 537) = 4.685$, $p < .05$; Fig. 1), but failed to observed significant main effects (hand, $F(1,537) = 1.588$, n.s.; sex $F(1, 537) = 1.796$, n.s.). Post hocs (Tukey's) indicated that left-handed males had significantly elevated scores compared to either left-handed women or right-handed men (p's $< .05$; Fig. 1). There were no other significant differences.

A $2 \times 2 \times 2$ ANOVA was performed using sex (M, F), handedness (right, left), and BDI depression cutoff recoding (below 10 or above 10 on the BDI) on the actual BDI scores. As was the case in the previous analysis, there was a significant interaction between sex and hand ($F(1, 533) = 13.063$, $p < .05$). However, there was a significant three-way interaction between sex, hand, and recoded BDI ($F(1, 533) = 6.409$, $p < .05$; Fig. 1). Not surprisingly, post hocs (Tukey's) indicated that the four depressed groups had significantly greater BDI scores than the nondepressed groups. Within the four depressed groups, the left-handed males had significantly higher BDI scores than the other three groups (Fig. 1). There were no other significant differences among the groups. Of interest, within the nondepressed groups the pattern of results was the same as was observed within the depressed groups. That is, similar to the depressed group of left-handed males, the nondepressed left-handed males also appeared to have elevated scores relative to the other three nondepressed groups.

Discussion

In the present study, only left-handed males endorsed significantly more depressive symptoms on the BDI. Previous research in this area suggests three possible explanations for our result: (1) atypical laterality of affective processing in left-handers; (2) a relationship between sex-role behaviors and handedness; and (3) nd differential steroid hormone levels in left-handers (particularly males).

Several investigators have suggested that altered patterns of hemispheric laterality are associated with mood disorders and left-handedness. Although this appears to be consistent with the notion that both depressed individuals and left-handed individuals share highly active right hemispheres, these assertions do not stand up to careful scrutiny. Depressed individuals exhibit decreases in right hemisphere activity, as indicated by deficits on visuospatial tests (Flor-Henry, 1976) and failures to show the normal left ear (right hemisphere) advantage for dichotic-listening tasks employing musical tones or click stimuli (Bruder et al., 1981; Johnson & Crockett, 1982). There is very little evidence suggesting that left-handers and right-handers differ in terms of cerebral lateralization for emotional processing (Bryden, Free, Gagne, & Groff, 1991). Even if the left-handers in our sample exhibited atypical lateralization of emotional processing, it is unclear as to what effect reduced right hemisphere activity would have on mood. Furthermore, the overwhelming evidence that the right hemisphere is specialized for negative affect leads one to expect that depression would be associated with hyperactivation of the right hemisphere, not hypoactivation.

Overby (1994) observed a significant increase in the incidence of left-handed women in a sample of depressed individuals, a result we failed to replicate. Overby attributed his result to conflicts between sex-role behavior and handedness. This result was first reported by Casey and Nuttall (1990), who found that left-handed women were significantly more masculine and less feminine than right-handed women. If sex-role conflict accounts for the present result, it is unclear as to why left-handed males (but not left-handed females) scored significantly higher on the BDI.

A few studies have indicated that steroid hormones levels are related to depression (e.g., Herzog, 1989). Consistent with this observation, there are several reports indicating that left-handers have lower testosterone levels, both prenatally (Grimshaw, Bryden, & Finegan, 1995) and postnatally (Moffat & Hampson, 1996). As we did not measure hormone levels, we cannot comment on the relationship between steroid hormones and mood in our sample. Although speculative, future studies could investigate whether lower levels of steroid hormones observed in left-handed individuals contribute to the elevated BDI scores in left-handers.

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Word Valence, Attention, and Hemispheric Activity in Depressed, Remitted, and Nondepressed Controls

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Clinically depressed ($n = 20$), previously depressed ($n = 28$), and nondepressed control ($n = 27$) individuals, classified according to a structured clinical diagnostic interview, participated in a study employing a modified *prior entry* (Titchener, 1908) procedure to investigate interrelationships among word (adjective) valence, visual attention, and cerebral hemispheric activity. Overall, positive words were selected more quickly when presented to the right, versus left, visual field (RVF, LVF); the opposite pattern was observed for negative words. While there was no significant group × Valence × Visual Field interaction, planned comparisons revealed that the aforementioned Valence × Visual Field interaction was significant only for the nondepressed control group. Although the remitted group exhibited an overall pattern similar to the control group, the depressed group evinced a pattern in the *opposite* direction for positive words (i.e., quicker in the LVF than the RVF).

Introduction

There have been several recent efforts to explore hemispheric differences in information processing as a function of the information's affective valence (e.g., Borod, 1992; Davidson, 1993). Although such research has generally suggested that emotion-laden information is processed differently by each cerebral hemisphere, a clear consensus regarding the nature of this lateralization effect has not yet emerged. For example, some researchers have proposed that the right hemisphere is dominant in (or specialized for) the processing of emotional information (e.g., Borod, 1992). In the *valence effect theory*, however, it is suggested that the left hemisphere specializes in processing positive material, while the right hemisphere is adapted to the processing of negative stimuli (e.g., Davidson, 1993). Moreover, it is unclear if hemispheric specialization is different for people with depression or other mood disorders. Beck's cognitive model proposes that depressed individuals exhibit a bias for processing negative information (Beck, 1976; Beck, Rush, Shaw, & Emery, 1979), a contention for which there is considerable empirical support. This negative bias appears to be quite pervasive, leading depressed people frequently to hold a negative view of themselves, their experiences, and the future. Other research has demonstrated that nondepressed individuals, in contrast, exhibit an attentional preference for positive material (e.g., Kakolewski, Crowson, Sewell, & Cromwell, 1999).

The temporal stability of such processing biases, however, is unclear. Does someone who has previously had a depressive episode (now in remission) continue to demonstrate a preference for negative information or a preference for positive information? In other words, is the suggested negative bias in depressed individuals a trait-like characteristic of the individual or a by-product of the depressed state? Such knowledge could enhance our understanding of depressive etiology and consequently treatment and relapse prevention methods. Some previous research has shown the salience for negative stimuli among those with depression to be a state- rather than a trait-like characteristic, which indicates that cognitively, remitted individuals may appear more like nondepressed controls (e.g., Ilardi & Craighead, 1999).

With the present study we aim to explore the relationship between hemispheric processing of emotion, attentional preferences, and mood states. Specifically, the goals for the present study are:

1. To determine if depressed participants show greater accessibility to negatively valent information;
2. To examine hemispheric differences in emotional processing with positive and negative adjectives; and
3. To determine if remitted subjects show lexical processing of valent information that is more like depressed or nondepressed individuals.

Method

Introductory psychology students at a mass testing session completed the Beck Depression Inventory (BDI; Beck, 1978), a 21-item self-report measure of depression. Also completed was a series of written questions based upon the *Diagnostic and Statistical Manual of Mental Disorders-Fourth Edition* (*DSM-IV;* American Psychiatric Association, 1994) major depressive episode criteria. Such criteria include depressed mood, loss of pleasure, appetite changes, difficulty sleeping, psychomotor agitation or retardation, fatigue, feelings of worthlessness or guilt, difficulty thinking, and suicidal thoughts.

Students were eligible for study inclusion if they met at least one of the following screening criteria: (1) a score of 18 or above on the BDI (indicative of clinically significant depressive symptomatology); (2) endorsement of at least five of the *DSM-IV*-based symptoms at some time in the past; or (3) a score below nine on the BDI and no endorsement of present or past the *DSM-IV* depressive symptoms. Potential participants were contacted and invited to participate in the current study. All included participants were right-handed and received experimental credit as part of a course requirement.

At the beginning of the experimental session, each participant was administered the mood disorders module of the Structured Diagnostic Interview for *DSM-IV* Clinical Version (SCID-CV; First, Spitzer, Gibbon, & Williams, 1997). The SCID-CV provided the basis for placing participants into one of the three groups according to the following criteria:

1. Depressed group (n = 20)—diagnosed with major depressive disorder, current, at the time of the interview;
2. Remitted group (n = 28)—diagnosed with major depressive disorder, in remission, at the time of the interview (endorsed previously having a depressive episode, but not within the month prior to the interview); and
3. Control group (n = 27)—did not meet criteria for either a current or a previous episode of depression.

In the final portion of the experimental session, participants completed a computer task requiring them to look at a computer monitor through a viewing box. The opening to the viewing box was 49 cm from the front of the monitor and shaped like a pair of goggles. The viewing box contained a vertical partition down the center, which was designed to help inhibit exposure of the stimuli contralaterally to the alternate retinal field. Each trial began with 3 s of a blank screen followed by one fixation cross on each side of the vertical partition in the center of the screen. After 1 s, a pair of adjectives was presented, one in each visual field, on either side of the fixation crosses. The word pairs were one of four types: positive–negative (PN), negative–positive (NP), positive–positive (PP), or negative–negative (NN). In the same valence conditions, the same word was presented to each visual field. The adjectives were obtained from a list by Meyers (1980) and are matched in terms of length and frequency. There were 18 trials for each word pair combination. The words and crosses were shown together for 730 ms. Finally, different colored bars (red, blue, or green), presented at the same height with one on each side of the screen, replaced the words and crosses. Then, participants pressed one of two keys (the ''z'' or the ''m'') depending upon which color bar was perceived to come onto the screen first.

Results

One set of analyses was conducted using reaction time (RT) as the dependent variable with diagnostic group, valence of the chosen word (Valchosen), valence of the other word (Valother), and visual field (VF) as the independent variables. A significant interaction between Valchosen × Valother was observed ($F(1, 72) = 19.40$, $p < .01$). Upon examining these data (see Fig. 1), it can be seen that the interaction is driven by a significantly quicker RT by all participants to NN and PP trials, compared with PN and NP trials. This pattern is consistent with the idea of ''redundancy gain,'' which refers to a processing advantage that is exhibited when the same information is presented to both visual fields rather than only one visual field (e.g., Boles, 1987).

There was also a significant Valchosen × VF interaction ($F(1, 72) = 5.95$, $p < .05$). Participants demonstrated faster RT to negative words when they were presented in the left visual field (LVF). Moreover, positive words yielded a faster RT when presented in the right visual field (RVF). Due to our interest in differences in this pattern across groups, the Group × Valchosen × VF interaction was examined. Although this three-way interaction was not significant, planned comparisons yielded a significant two-way Valchosen × VF interaction only for the nondepressed control group ($F(1, 72) = 4.62$, $p < .05$). The pattern of the means for the depressed participants was in the same direction for the negative words, but in the *opposite* direction

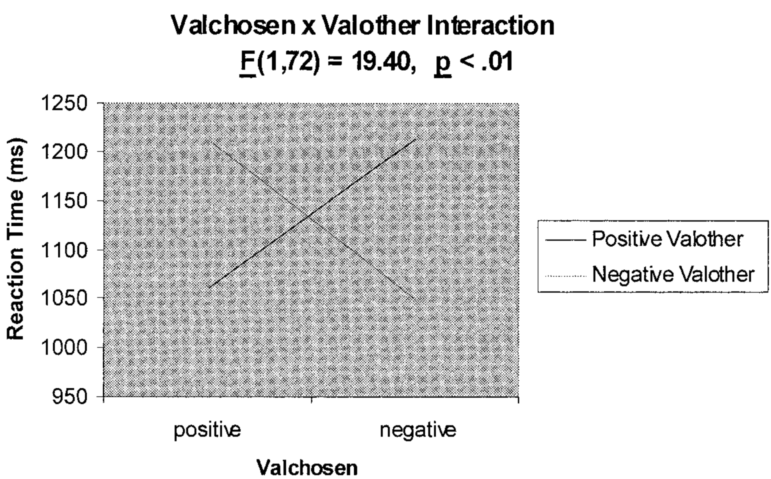

FIG. 1. Interaction between valence of the chosen word and the valence of the other word across groups.

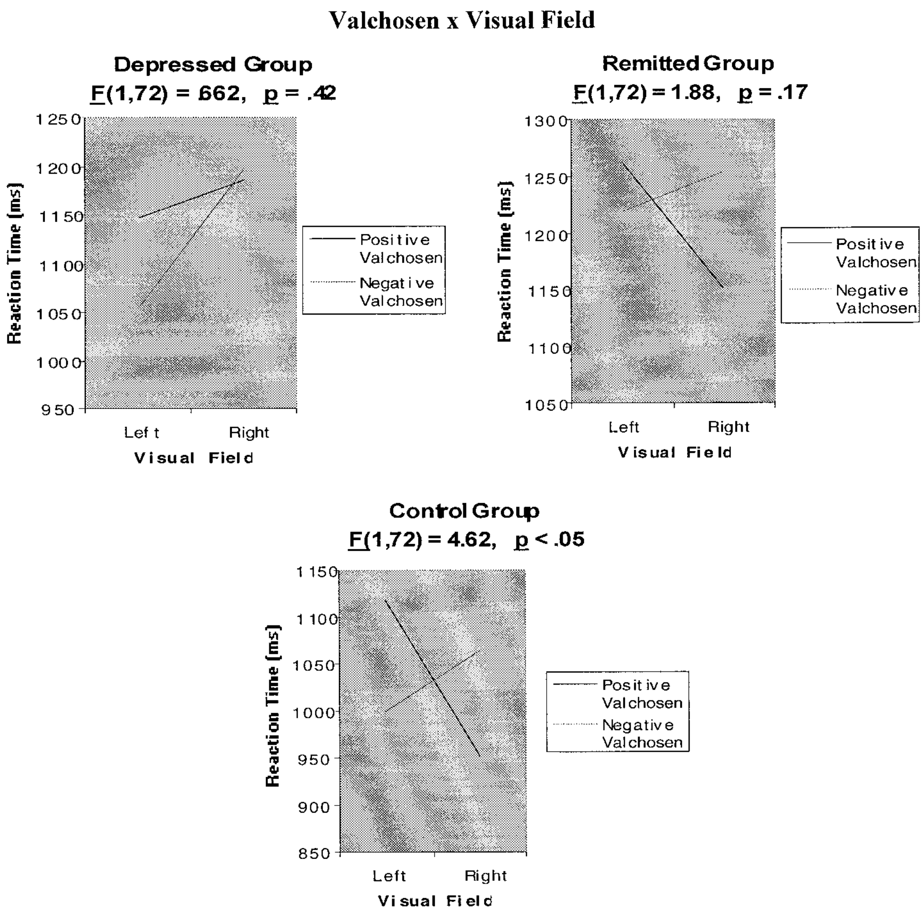

FIG. 2. Interaction of valence of chosen word and visual field for each group of participants.

for positive words (see Fig. 2). In other words, there did not appear to be a RT advantage for positive words in the RVF. The pattern of means for the remitted group appeared similar to that of the control group, but only the comparison of positive words in the right versus left hemisphere exhibited a trend toward statistical significance ($F(1, 72) = 3.23$, $p = .07$).

Another set of analyses was performed using choice of the positive word as the dependent variable. In these analyses, only the NP and PN trials were included. Group and VF were the independent variables. Neither main effect nor the Group × VF interaction was significant. However, the main effect for group showed a trend toward significance ($F(2, 72) = 2.53$, $p = .08$). A planned comparison was performed between the depressed and control groups was significant ($F(2, 72) = 4.65$, $p < .05$). The data indicate that the control group has a slight preference for choosing the positive word (54.9%), while the depressed group demonstrates a slight preference for choosing the negative word (52.5%). Overall remitted participants chose positive and negative words with equal frequency.

Discussion

The current study suggests that negatively valent adjectives may be processed more quickly when presented in the LVF or right hemisphere. Moreover, positively valent adjectives appear to be associated with a processing advantage when presented in the RVF or left hemisphere. Such results are consistent with the *valence effect theory* (e.g., Davidson, 1993). In other words, the present data lend support for the notion that the right hemisphere is specialized for processing negatively valent information, while the left hemisphere is specialized for positive information.

However, while this overall picture seems true of nondepressed control participants, it is less clear when looking at our study's depressed and previously depressed individuals. The reaction time pattern exhibited by the remitted group was visually similar to the control group, but did not reach statistical significance. Furthermore, the depressed group did not show the processing advantage for positive or negative information in the left and right hemispheres, respectively. Therefore, this study does not support the valence effect theory in people with depression or those who have previously been depressed. It should be noted that the long presentation time of the word pairs might make it more challenging to find hemispheric effects with this task. Therefore, future researchers may wish to employ more stringent control over visual field presentation in order to help evaluate differences among depressed, remitted, and control participants.

Regarding the concept of attentional preferences or biases, a trend was found indicating that the control group chose more positive words, while the depressed group chose more negative words. Such a finding is in line with Beck's cognitive theory (Beck, 1976; Beck, Rush, Shaw, & Emery, 1979) that states that depressed people have a negative outlook that may lead them to exaggerate negative information and possibly to ignore or overlook positive information. Meanwhile, never-depressed individuals appear to seek out more positive than negative information. The attentional preferences of previously depressed (remitted) individuals people are less clear, though the overall group mean suggests equal visual attention allocated to positive and negative material among such individuals.

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Spatial Strategy Elaboration in Egocentric and Allocentric Tasks Following Medial Prefrontal Cortex Lesions in the Rat

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We evaluated the role of the medial prefrontal cortex (mPFC) in the elaboration of egocentric navigation strategies in a water maze (WM). Lesions of mPFC cell bodies was achieved in 21 rats using bilateral injections of ibotenic acid (IA); 13 control rats were injected with saline. After 17 days, rats had to learn an allocentric (using external cues: 10 lesioned, 7 saline rats) or an egocentric WM (using internal/kinetic cues: 10 lesioned, 6 saline rats) over six trials in a same session. The initial trajectory on the sixth trial was used as an index of the elaboration of a navigation strategy. In the egocentric test, lesioned rats were more rarely located in the target quadrant than control rats. No differences were found between lesioned and control rats in the allocentric test. These results show that lesions of the mPFC impairs the capacity to elaborate an egocentric navigation strategy.

According to de Bruin et al. (1997) the medial prefrontal cortex (mPFC) plays a role in setting up egocentric but not allocentric cognitive maps in water maze (WM) tasks. Until now the role of the mPFC was based on gross nonspecific lesions techniques (cortical suction, radiofrequency lesions, etc.) severing fibers of passage, etc. The aim of the present study was to verify the role of mPFC in the elaboration of egocentric navigation strategies.

Method

Thirty-four young male Sprague–Dawley rats (350–400 g) were used. Selective excitotoxic lesions of mPFC cell bodies was performed in 21 rats using microinjections of ibotenic acid (IA) while 13 control rats were injected in the same region with saline. Ten days after surgery, rats were tested with either an allocentric (10 lesioned rats, 7 controls rats) or an egocentric WM task (10 lesioned rats, 6 controls rats). Lesions were confirmed by standard histological methods.

Procedure

On each trial of the *allocentric* WM test, rats started from a different quadrant of the pool relative to the previous trial while the hidden target platform always stayed at the same place. This procedure calls for the use of external cues in order to succeed. In the *egocentric* version the platform was always positioned in a straight line relatively to its starting position, which was located in a different quadrant from the previous trial. This procedure calls for the use of internal/kinetic cues in order to succeed. The rats had six trials of 60 s maximum to reach the hidden target platform where they remained for 30 s. Upon an unsuccessful trial, the experimenter placed the rat on the platform for 30 s. The dependent measure was based on an analysis of the animal initial trajectory. We know from a WM pilot study that naive rats need two quadrants to find a visible platform. Therefore, we analyzed the initial part of each rat's trajectory to verify if it was in the target area, e.g., in the quadrant containing the hidden platform, after two quadrant entries.

Results

Allocentric WM. There was no difference between lesioned and control rats; i.e., there was an equal proportion of rats from the two groups in the target quadrant (saline, 100%; lesioned, 80%, n.s.).

Egocentric WM. Lesioned rats were less frequently found in the target quadrant compared to control rats (saline, 50%; lesioned, 9%, χ^2 (17.67, $df = 1$), $p < .00003$). Lesioned rats were neither found in the previous trial's target quadrant. Rather, 9/11 (88.1%) of the lesioned rats were found in the starting quadrant.

Discussion

We found no difference between control and lesioned rats in the allocentric WM while mPFC rats were impaired in the egocentric WM. In the egocentric WM test, behavioral analysis showed that lesioned rats were neither located in the previous trial's target quadrant, suggesting that they also did not use an allocentric navigation strategy as an alternative. The fact that they were located back in the starting quadrant could suggest that rats with a lesion of the mPFC are not capable of correcting a deficient navigational strategy as it is being elaborated and that they choose to home the starting position upon navigational strategy difficulties.

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Hemispheric Processing Asymmetries: Implications for Memory

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Recent research has demonstrated that memory for words elicits left hemisphere activation, faces right hemisphere activation, and nameable objects bilateral activation. This pattern of results was attributed to dual coding of information, with the left hemisphere employing a verbal code and the right a nonverbal code. Nameable objects can be encoded either verbally or nonverbally and this accounts for their bilateral activation. We investigated this hypothesis in a callosotomy patient. Consistent with dual coding, the left hemisphere was superior to the right in memory for words, whereas the right was superior for faces. Contrary to prediction, performance on nameable pictures was not equivalent in the two hemispheres, but rather resulted in a right hemisphere superiority. In addition, memory for pictures was significantly better than for either words or faces. These findings suggest that the dual code hypothesis is an oversimplification of the processing capabilities of the two hemispheres.

Observations of patients with unilateral brain lesions hint at a multitude of functional asymmetries between the two hemispheres of the brain. Paul Broca first noted the left hemisphere's dominance for language after an autopsy on his famous aphasic patient, Tan. Other syndromes resulting from unilateral brain damage also sparked interest in the specialized functions of the two cerebral hemispheres. Patients with right parietal damage would ignore the right half of visual space and, to the amazement of their families and doctors, might only dress one half of their bodies or put makeup on the right side of their faces. These types of startling patient profiles led many researchers to begin to think about functional differences between the two hemispheres.

Research with patients who have undergone surgical separation of the two cerebral hemispheres, so-called ‘‘split-brain’’ patients, has confirmed and extended many of the findings from lesion patients and revealed much about the specialized functions of the two hemispheres. Early investigations confirmed the left hemisphere’s specialization for language and demonstrated the right hemisphere’s superiority for visuospatial functions. These differences in the way that the two hemispheres process information have potential implications for the way information is encoded. The two hemispheres might ‘‘remember’’ different aspects of events and split-brain patients might demonstrate deficits in various memory tasks. Although early studies demonstrated that callosotomy does not result in any general decrement in memory, subsequent research revealed specific memory functions that are affected by hemispheric separation. Phelps, Hirst, and Gazzaniga (1991) demonstrated that although callosotomy patients are not impaired in recognition memory, they are impaired in free recall. They speculate that the two hemispheres process and store different aspects of events, and therefore disconnecting the two hemispheres results in a degradation of the resulting mnemonic representation.

A number of researchers have further investigated the effect of hemispheric processing differences on memory. Kroll and colleagues tested callosotomy patients on memory for different types of stimuli (Jha, Kroll, Baynes, & Gazzaniga, 1997). They found that callosotomy patients are not impaired on verbal memory tasks, but do demonstrate significant deficits in memory for pictorial information. The authors conclude that the left hemisphere encodes the elements of verbal memories independently of the right hemisphere whereas memory for pictorial information requires integration between the two hemispheres. Consequently, callosotomy is detrimental to memory for pictorial information but not verbal information. This finding is consistent with previous research demonstrating differences in verbal and nonverbal memory in patients with unilateral brain lesions (Kroll, Knight, Metcalfe, et al., 1996).

Recent research by Kelley and colleagues is consistent with the idea of a dual coding of stimuli (verbal and nonverbal). They investigated the neural substrates of memory encoding using functional brain imaging (Kelley, Miezin, McDermott, et al., 1998). Subjects were presented with words, line drawings of common objects, and pictures of unfamiliar faces and asked to try to remember them for a subsequent memory test. Each category of stimuli elicited activation in dorsal frontal regions, but the lateralization of the activation differed depending on the type of stimuli being encoded. Encoding of words resulted in left frontal activation whereas encoding of faces resulted in right hemisphere activation. The line drawings of common objects, however, resulted in bilateral activation. The authors conclude that the left hemisphere is dominant for encoding of verbal information, whereas the right is superior for nonverbal encoding. Pictures of nameable objects can be encoded both visually and verbally, so both hemispheres have a mechanism available for encoding of this class of stimuli.

Based on these findings, it would be expected that the left hemisphere of split-brain patients would be superior to the right in memory for verbal information, whereas the right hemisphere would be dominant in memory for unfamiliar faces. There should be no significant difference between the two hemisphere in memory for line drawings of common objects since these can be encoded both visually and verbally. These predictions were tested in a series of experiments with a patient with a complete callosotomy.

Methods

Callosotomy patient J.W. participated in the reported experiments. J.W. is a 46-year-old right-handed man who underwent two-stage resection of the corpus callosum for the relief of intractable epilepsy in 1979. Further details of his medical history can be found in Gazzaniga, Nass, Reeves, and Roberts (1984).

The study sets consisted of 10 items presented center field for 3 s each. There was a 1.5-s interval between study items. Following each study set, there was a 4-min interval in which J.W. was asked to make simple visual discriminations as part of a separate experiment. J.W. was then presented with a test set which included the 10 items he had studied and 10 new items. Each item appeared once in the right visual field and once in the left, resulting in a total of 40 items in the test set. On each trial J.W. indicated whether he recognized the item as belonging to the study set by pressing a button on the computer keyboard.

J.W. was seated approximately 57 cm in front of a computer screen and told to fixate a central cross-hair. Stimuli were flashed to either the right (RVF) or left visual field (LVF) for 150 ms to ensure that stimuli are perceived only by the hemisphere contralateral to the visual field of the presentation.

There were a total of six study/test sets: two each of pictures, faces, and words. The pictures and words were taken from the set published by Snodgrass and Vanderwart (1980). The faces were provided courtesy of M. J. Tarr (Brown University, Providence, RI). J.W. was tested on each set four times, with at least 1 week between each testing session. The hand used to respond was counterbalanced between blocks.

Results and Discussion

Only responses made with the hand ipsilateral to the stimuli were analyzed. In other words, for left-hand blocks only responses to left-visual-field stimuli were included in the analysis and vice versa. This helped to ensure that the stimulated hemisphere generated the response. J.W.'s response accuracy for stimuli presented to each visual field in each task is shown in Fig. 1.

Because this experiment involves analysis of data collected from a single observer in which each hemisphere serves as a control for the other, statistical tests were carried out on J.W.'s responses using a hierarchical χ^2 analysis (Winer, Brown, & Michels, 1991). The factors in this analysis were Condition (old vs new), Response (''old'' vs ''new''), Visual Field (LVF vs RVF), and Task (pictures vs words vs faces). In this analysis, response accuracy is indexed by the contingency between Condition and Response, and ''interactions'' involving accuracy are indexed by higher-order contingencies between Condition, Response, and other factors.

The χ^2 analysis revealed a significant contingency between Condition and Response (χ^2 (1) = 90.13, $p < .001$), which indicates that J.W. was performing the memory task accurately overall (overall accuracy = .717). The contingencies between Task, Condition, and Response (χ^2 (2) = 22.82, $p < .001$) and Task, Field, Condition, and Response (χ^2 (2) = 7.35, $p < .05$) were also significant. The first of these reflects different overall levels of response accuracy in the three tasks (pictures, .868; words, .663; faces, .619). The four-way contingency reflects the fact that the effect of visual field on response accuracy was not the same in each task. In the pictures and faces tasks responses were more accurate for LVF stimuli than for RVF stimuli (pictures, LVF = .938, RVF = .800; faces, LVF = .688, RVF = .550). By contrast, in the words task performance was more accurate for RVF stimuli (.725) than for LVF stimuli (.600). Post hoc tests were carried out in which the data from

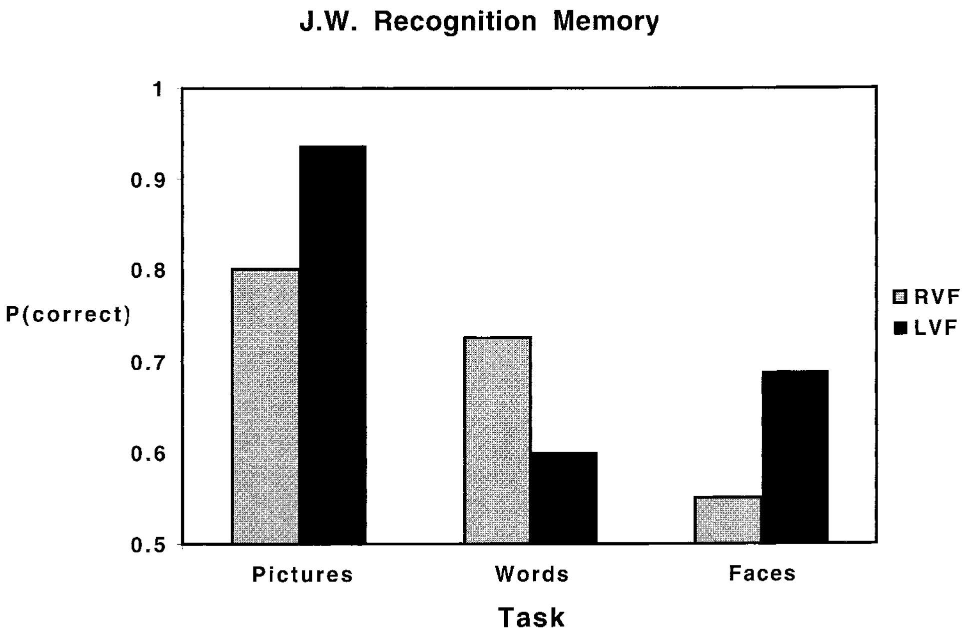

FIG. 1. J.W.'s recognition performance in the pictures, words, and faces tasks. The proportion of correct responses in each task is shown separately for each visual field.

each task were removed from the calculation in turn. This analysis revealed that the four-way contingency between Task, Field, Condition, and Response was statistically significant for the comparisons between the words and pictures (χ^2 (1) = 5.51, $p <$ .05) and words and faces (χ^2 (1) = 5.51, $p <$ .05), but not between pictures and faces (χ^2 (1) = 0.00, n.s.). Thus it appears that the original four-way contingency was driven exclusively by the difference between the words task and the other two tasks—the effects of Visual Field on accuracy did not differ between the pictures and faces tasks.

These results suggest that the memory trace for words is lateralized differently from those for faces and pictures. As predicted, memory performance for words is better when the test stimuli are presented to the RVF (left hemisphere) than when they are presented to the LVF (right hemisphere). The opposite pattern was obtained for the faces task and, somewhat surprisingly, for the pictures task. For both these tasks test stimuli presented to the LVF (right hemisphere) resulted in better recognition than stimuli presented to the RVF (left hemisphere). Although pictures were recognized better than faces, the lack of a significant four-way contingency between Task, Field, Condition, and Response for the comparison between pictures and faces suggests that the memory traces are similarly lateralized.

General Discussion

At the outset of the experiment we anticipated that the left-hemisphere specialization for language would result in an advantage for recognizing words. Similarly, we expected that the right hemisphere would exhibit stronger memory for faces. Both these expectations were confirmed. However, we also anticipated that the hemispheres would be equivalent for the pictures task since both verbal and nonverbal codes would be available. Instead, we found that the lateralization pattern of recognition memory for nameable pictures was similar to that for faces, with the right-hemisphere recognition performance superior to the left. Levels of accuracy in both hemispheres, however, were significantly higher for pictures than for either words or faces.

The results of this experiment suggest that a dual-code model may be an oversimplification of the processing capabilities of the two hemispheres. Instead, each hemisphere brings to bear a variety of processing resources, with each contributing to the memory trace. If the left hemisphere had only the verbal code available, then there should be no difference in level of accuracy on words and pictures. The pictures should simply be stored as verbal labels. This, however, was not the case in this experiment. Similarly, if the right hemisphere had only a single nonverbal code available, then there should be no difference in recognition for faces and nameable objects. Because both hemispheres were better able to remember nameable objects than either words or faces, this suggests that each hemisphere has a variety of processing capabilities, and these are reflected in the memory trace for different categories of stimuli.

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Imagined and Actual Limb Selection: A Test of Preference

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Imagined and actual motor performance were compared to determine what factor(s) drive limb selection for programming movements in contralateral hemispace. Forty right-handed blindfolded subjects were asked to ‘reach’ via auditory stimulus for a small object placed at multiple locations in hemispace. Two conditions were included: arms uncrossed and arms crossed. With the uncrossed condition, responses were similar. With arms crossed, subjects had the choice of keeping the limbs crossed, reacting to proximity, or uncrossing the arms to reach ipsilaterally. In this condition subjects ‘imagined’ that they would maintain the crossed position and reach with the hand closest to the stimulus in both right and left hemispace. However, during 'actual' reaching, responses differed. For left-field stimuli, participants kept the arms crossed, but in response to right-field stimuli, subjects preferred to uncross the limbs in order to reach with the dominant hand. These findings suggest that while motor dominance is the primary factor in limb choice for action in ipsilateral hemispace, it appears that object proximity drives limb selection for reaching in contralateral hemispace.

Our aim with the present study was to examine the relationship between imagined limb selection and overt action. Recent studies suggest that imagined and actual movements share common neurocognitive networks (e.g., Decety, 1996) and with manual tasks, such actions are controlled primarily by the hemispheres contralateral to the imagined limb (Maruff et al., 1999). Therefore, the question arises, does imagined and actual limb selection differ and how could this information be used to explain hand preference? Although motor dominance has been shown to be a strong factor in determining choice of limb for reaching and grasping movements at the midline and dominant (ipsilateral) side hemispace, other factors have been tied to programming goal-oriented actions in contralateral space, namely, attentional information derived from object proximity information (Rosenbaum, 1991; Stins & Michaels, 1997) and a hemispheric bias for using the hand on the same side as the stimulus-in ipsilateral fashion (e.g., Simon, 1969; Verfaellie & Heilman, 1990; and noted in infants studies, Perris & Clifton, 1988; Robin, Berthier, & Clifton, 1996).

To accomplish our goal, imagined and actual motor performance were compared as blindfolded subjects were asked to 'reach' via auditory stimulus for a small object placed at multiple locations in hemispace. In addition to the typical ipsilateral position (Fig. 1a) used as a control, an arms-crossed condition was included (Fig. 1b). With

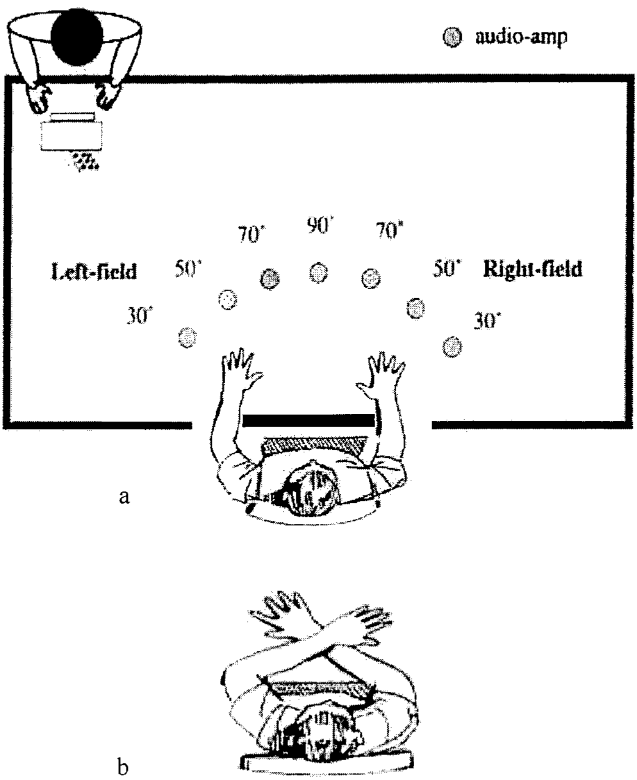

FIG. 1. The experimental setup and arm positions: (a) uncrossed; (b) arms crossed.

this condition, the subject had the choice of uncrossing the limbs to reach ipsilaterally. The question was, will subjects program selection based on proximity of hand to object location, thereupon keeping the arms crossed while reaching? Or, will they uncross the arms in preference to working in ipsilateral hemispace, lending support for a hemispheric bias? And, will imagined and actual performance differ? According to the motor imagery literature, responses should be similar. However, we predicted that a difference (conflict) was possible considering that from a cognitive perspective, keeping the arms crossed is arguably the more efficient mode of reaching in this context—since it is closer to the object.

Method

Subjects consisted of 40 right-handed university student volunteers. Initially, each subject completed the hand preference section of the Lateral Preference Inventory questionnaire (Coren, 1993) and for the purposes of this study, only subjects identified as strong right-handers; i.e., those for whom all items were scored in the right direction were included in the investigation. For a detailed description of the testing apparatus refer to Rabb and Gabbard (1999).

To examine the primary research question, two tasks were conducted: imagined and actual performance, both using the crossed and uncrossed arm positions. Order of stimulus position (object location) was systematically given using a computer-generated list of random positions, counterbalanced between subjects. To ensure that limb selection was not altered by factors such as which limb was on top or which hand was previously used, two trials at each position were given for both conditions in the two tasks. In addition, if choice of limb was not replicated for both trials, a third trial was administered for the position. In this case, the limb that was used two of three trials was recorded. Previous work determined that limb selection rarely varied for the same location; test–retest concordance ranged from 84 to 99% over 3 to 5 days using two trials at each position for two sessions. Both tasks were given in a single testing session and subjects remained blindfolded for the duration.

Task 1: imagined movement. Figure 1a shows the typical uncrossed limb reaching position. For the arms-crossed condition subjects were instructed to cross their limbs allowing approximately 5 cm clearance from the table and about 2.54 cm between arms (Fig. 1b). They were asked not to respond until after the two tone per second stimulus (delivered at a frequency of 2.484 kHz) which was preceded by a ''Ready'' signal. Following the stimulus, subjects were required to wave the fingers of the hand that they imagined they would use to reach to the stimulus; no other movement was allowed. That is, subjects were instructed to imagine themselves moving without actual reaching. One limb remained on top throughout the duration of the trial and this was switched for the second trial.

Task 2: actual movement. To begin, subjects were asked to acquaint themselves with both conditions (without experimental stimuli) with the intent of maximizing reaching comfort. Reaching distance was systematically measured and set for each subject. In order for the limb selected to be recorded, the subject had to be no more than one hand width off target on initial reach. Pilot testing revealed that subjects were quite accurate at localizing (differentiating between) each of the seven positions presented. For the uncrossed condition, subjects had arms uncrossed and resting in hand rests on table and a 2.54-cm cube was placed at one of seven locations. Subjects were asked to reach for the cube after the tone and place it in a box at the midline. Speed was not be emphasized, but instead subjects were asked to respond in their own reasonable time. Body position procedures for the arms-crossed condition were like that in Task 1, with the addition of actual reaching, performed by either uncrossing the arms to reach for the cube or keeping the arms crossed. In regard to position 'comfort,' of 30 pilot subjects, only 4% (left field) and 3% (right field) rated arms-crossed reaches as 'awkward.' In the pilot, a 10° position was tested, but eliminated for the present experiment.

Results and Discussion

Figure 2 presents graphic illustrations of uncrossed and crossed arm condition profiles.

Imagined versus actual movement—uncrossed condition (Fig. 2, top). Results for this condition are rather straightforward. In reference to imagined movement, most subjects imagined that they would reach with their dominant (right) hand at the midline (92.5%) and right-field (100%) positions. However, with left hemispace responses, frequency of dominant hand imagined use drastically decreased as stimulus location moved away from midline (22.5, 2.5, and 0%, respectively). In essence, an overwhelming 92% imagined that they would switch to their left, nondominant

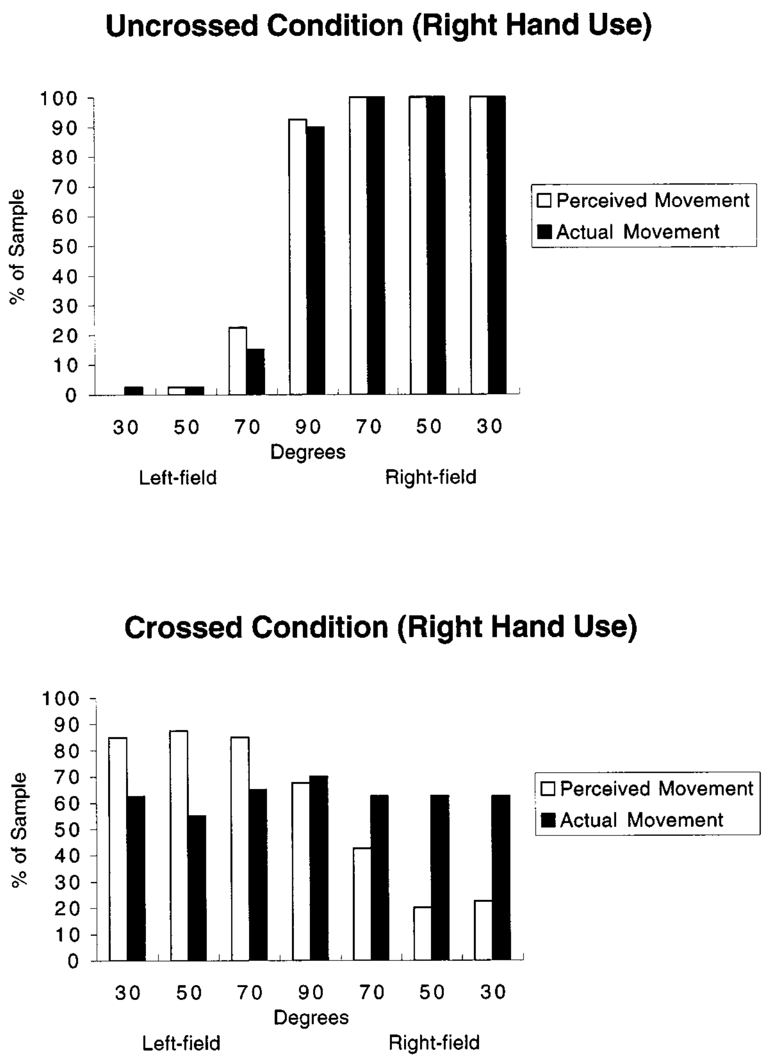

FIG. 2. Response profiles for imagined and actual movement: (top) uncrossed; (bottom) arms crossed.

limb, in response to left hemispace stimuli. In regard to actual movement with the limbs uncrossed, these data support earlier findings (Gabbard et al., 1997, 1998). That is, subjects used their dominant (right) hand at the midline (90%) and right-field (100%) positions. In left hemispace, however, frequency of right hand use decreased as stimulus location moved away from midline (15, 2.5, and 2.5%). In other words, 93% of participants switched to use their nondominant (left) hand at corresponding left hemispace positions. All χ^2 tests for comparison of right- and corresponding left-field position responses within task were significant (ps $< .001$); however, comparisons between imagined and actual performance found no difference at any position (ps $> .30$).

Considered together, these results replicate the findings of previous work in our lab and support both object proximity and a hemispheric bias for using the hand on the same side of the stimulus. In addition these data also lend support to the notion that imagined and actual movement programming are at least similar.

Imagined versus actual movement—crossed condition (Fig. 2, bottom). The arms-crossed condition was designed to distinguish empirically between behavior based on proximity or a hemispheric bias for ipsilateral movement. To support the proximity hypothesis, subjects would perceive that they would use the hand closest to the object and, thus, keep the limbs crossed. However, to support the hemispheric bias, subjects would perceive that they would use the hand on the same side of the object and, thus, uncross the limbs. In addition, the imagined arms-crossed condition was designed to investigate the possibility that imagined and actual movement may be different. Without actual movement, it was predicted that subjects would perceive that they would use the hand closest to the stimulus, thus supporting the proximity hypothesis.

For imagined responses to right-field stimuli, an average of 72% of subjects imagined that they would remain in the crossed position, thus selecting the hand of closest proximity to the object, in this case the left (nondominant) hand. In contrast, only 28% imagined that they would uncross their limbs in favor of performing the movement ipsilaterally, i.e., responding to right-field stimuli using their dominant right limb. Regarding left hemispace responses, 86% of subjects imagined that they would remain in the crossed position, while 14% imagined that they would uncross their limbs to reach ipsilaterally. χ^2 tests comparing imagined right- and left-hand responses were found to be significant at all positions (ps $< .001$).

In reference to actual movement in response to right-field responses, an average of 62.5% of subjects uncrossed their limbs in order to reach with the hand on the same side of the stimulus, in this case the right (dominant) hand. In contrast, only 37.5% remained in the crossed position while reaching, in order to use the hand of closest proximity to the object, in this case the left (nondominant) hand. Regarding contralateral (left hemispace) stimuli, 39% of subjects uncrossed their limbs to use the hand ipsilateral to the stimulus, in this case the left (nondominant) hand. In contrast, 61% remained in the crossed position while reaching using the hand closest to the cube, in this case the right (dominant) hand. χ^2 procedures revealed no significant difference between hand use across hemispace positions in the crossed condition ($p > .9$). In summary, these findings suggest that limb choice for programming contralateral movements is driven primarily by information derived from using the hand nearest to the stimulus.

Closing Remarks

While the uncrossed condition during imagined and actual movement supports both bias and proximity effects, results from the arms-crossed condition appear to shed new light on the mystery associated with limb selection. That is, most subjects 'imagined' that they would maintain the crossed position and reach with the hand closest to the stimulus in both right and left hemispace. However, during 'actual' reaching responses differed. When the object was placed in the left field, participants kept the arms crossed to reach with the hand closest to the stimulus, thus supporting object proximity. In response to right-field stimuli, subjects preferred to uncross the limbs in order to reach with the dominant hand. Therefore, these findings suggest that while motor dominance is the primary factor in limb choice for action in ipsilateral hemispace, it appears that object proximity drives limb selection for reaching in contralateral hemispace.

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Number–Stroop Performance in Normal Aging and Alzheimer's-Type Dementia

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The number–Stroop paradigm was used to investigate changes in the inhibitory system and in numerical processing in healthy elderly and individuals with dementia of Alzheimer's type (DAT). The size-congruity effect (i.e., relative to neutral trials, incongruent pairs interfere and/or congruent pairs facilitate either numerical or physical comparison) was found in all groups, though the pattern of interference and facilitation varied across them. Overall, the selective attention breakdown was reflected by the increase in interference shown by the older group and the DAT group. On the other hand, the observation of a standard laterality effect and of automatic numerical processing in all groups suggests that access and retrieval of numerical information is relatively resistant to cognitive deterioration.

Introduction

It is known that a general inefficiency of the inhibitory system characterizes both normal aging and DAT. In the Stroop task, the decline in efficiency emerges as an increase in interference from irrelevant dimensions of a stimulus. The standard color-word task, however, is not adequate to test patients with language difficulties or color confusion deficit, and alternative tests are required.

Recent evidence suggests that also numerical disorders should be included among the early signs of DAT, since over 90% of DAT patients seem to present some deficit in the numerical domain (Girelli & Delazer, in press). Whether these difficulties mainly concern specific calculation abilities or may extend to the semantic processing of numerals remains to be clarified.

We adopted a number–Stroop paradigm requiring subjects to compare either the numerical size (numerical task) or the physical size (physical task) of two Arabic numerals varying along both dimensions. The *size congruity effect* occurs in both tasks: incongruent physical size interferes with numerical comparison and incongruent numerical size interferes with physical comparison (Tzelgov, Meyer, & Henick, 1992). As a variation of the standard Stroop task, this paradigm provides a tool to investigate age- and dementia-related changes in inhibitory mechanisms. At the same time, it allows us to evaluate changes in processing numerical information, in particular providing information on the nature of number semantic representations and on the access to them (Girelli, Lucangeli, & Butterworth, forthcoming).

Thus, possible changes in the performance are assumed to result from general factors, such as decrease of selective attention mechanisms and of processing speed, as well as from differences in number processing. We expect the former to play a role in both normal aging and dementia, while the latter would emerge in DAT individuals' performance as a result of degraded number semantic representations.

Experimental Investigation

Method

Subjects. Sixty-four individuals participated in this study. Sixteen were patients recruited through the Alzheimer Centre in Brescia. Patients' inclusion and exclusion followed the NINCS–ADRDA criteria (McKhann et al., 1984). The degree of cognitive deterioration was evaluated through the Mini-Mental State Examination and the Clinical Dementia Rating Scale. Inclusion criteria were a diagnosis of very mild or mild DAT (i.e., MMSE score between 18 to 24 and a CDR score between 0.5 and 1). Patients had a mean age of 76.5 years. Forty-eight healthy controls participated in the study: 16 university students (mean age 23 years), 16 young-old adults (mean age 61.1), and 16 old-old adults (mean age 76.2).

Material

The standard ''distance effect'' (the more different the two numbers, the more rapid and accurate the response) was evaluated in terms of Tzelgov's criteria (1992). In this, the numbers are classified as small ($1 < x < 4$) or large ($6 < x < 9$). ''Unilateral'' pairs contained either two small numbers or two large numbers, separated by a distance of 1 (e.g., 1 2); in bilateral'' pairs, one number was small and the other one was large, and they were separated by a distance of 5 (e.g., 1 6). There were three different congruity conditions: (a) *congruent* when the numerically larger number was physically larger (e.g., 2 6); (b) *incongruent* when the numerically larger number was physically smaller (e.g., 6 2); or (c) *neutral* when the numbers were displayed in the same size (numerical comparison, e.g., 2 6) or the same numbers were displayed in different size (physical comparison, e.g., 2 2). Both tasks included two blocks of 60 stimuli each and 20 training trials. The position of the correct answer was balanced across trials and conditions.

Procedure

Subjects were presented with the numerical and physical tasks on different days; the order of presentation of the tasks was counterbalanced across subjects.

Each trial began with a fixation point followed 500 ms later by a pair of stimuli to be compared. Participants were instructed to press the left- or right-hand key according to the position of the ''larger'' number. In the congruent and incongruent conditions the physically larger digit was 12 mm height, and the physically smaller 6 mm height. In the neutral condition they had an intermediate size (9 mm). Stimuli stayed on the screen until the subject responded. Instructions emphasized both speed and accuracy. A microcomputer and specialized software were used to display stimuli and record RTs.

Results

Correct RTs only contributed to the analysis. For each task, RTs below or above 3 SDs from each individual's average RT were eliminated. This procedure eliminated 0.9% of responses for young adults, 1.4% for young-old adults, 1.2% for old-old adults, and 2.3% for DAT patients.

Table 1 shows average error rates for each group in the different experimental conditions. Overall error rates were low and fit the RTs data. Physical comparison (1.3%) was easier than numerical comparison (3.5%). In the numerical task, errors increased from 1.4, 1.8, and 7.2% across congruent, neutral, and incongruent conditions. In the physical task there were 0.6% errors, 1.2 and 2.1% in the congruent, neutral, and incongruent conditions. Error rate increases with age and reached 5.8% in the DAT group.

These observations were confirmed in an overall ANOVA. A significant group effect, $F(3, 60) = 33.52$; $p < .001$, indicated a latencies increase across the groups. Post hoc tests showed that each group differed from the other (all $p < .01$), apart from youngs and young-olds who performed similarly. The physical task was always faster than the numerical one (848 ms vs 1162 ms; $F(1, 60) = 33.97$, $p < .001$).

A series of ANOVAs were carried out separately for the two tasks to investigate the effect of age (comparing youngs, young-olds and old-olds) and of dementia (comparing patients and old-olds) on the size-congruency effect. All analyses yielded reliable group and congruency main effects. Only interactions are discussed in details.

Numerical Task

Aging effect. In a 3 × 3 ANOVA a significant group × congruency interaction was found, $F(4, 90) = 6.16$, $p < .005$. Decomposition into contrasts revealed that in both youngs and young-olds all congruency conditions differed from each other (all $p < .005$). However, in the old-olds, incongruent trials were slower than congruent and neutral ones (both $p < .001$), but the latter two did not differ. Thus, youngs

TABLE 1
Mean RTs and Error Rates for the Different Groups as a Function of Task, Congruency, and Laterality of the Pairs

	Numerical				Physical[a]			
	Unilateral		Bilateral		Unilateral		Bilateral	
	RT	% Error	RT	% Error	RT	% Error	RT	% Error
Young								
Congruent	652	0.0	567	1.5	453	0.0	454	0.3
Neutral	638	0.7	550	0.0	458	0.3	458	0.3
Incongruent	721	3.9	654	1.5	465	0.7	489	2.7
Young-old								
Congruent	827	0.0	736	0.3	597	0.0	595	0.0
Neutral	858	1.1	770	0.3	601	0.3	601	0.3
Incongruent	924	6.2	847	0.3	609	0.3	627	0.3
Old-old								
Congruent	1256	0.7	1153	0.7	913	2.3	921	1.1
Neutral	1266	0.0	1163	1.1	930	0.9	930	0.9
Incongruent	1395	4.6	1300	3.1	948	2.3	980	0.7
DAT								
Congruent	1832	3.9	1608	3.9	1328	1.9	1310	1.5
Neutral	1891	7.0	1795	4.6	1342	3.2	1342	3.2
Incongruent	2243	17.5	2063	15.2	1470	4.2	1538	5.1

Note. SDs varied from 61 to 135 ms in the young group, from 133 to 196 ms in the young-old group, from 386 to 504 ms in the old-old group, and from 409 to 1081 ms in the DAT group.

[a] Note that the neutral condition in physical comparison does not vary for laterality: for the sake of facilitating relevant comparisons identical values are reported in correspondence to unilateral and bilateral cells.

and young-olds showed a similar pattern of facilitation and interference while older adults showed an interference effect only. Inspection at the single-subject level revealed that only three subjects showed a clear advantage for the neutral condition compared to the congruent one, while the latter was the faster condition for all other individuals.

The analysis of the laterality effect indicated that bilateral pairs were answered faster than unilateral pairs $F(1, 45) = 65.75$, $p < .001$. The effect did not interact either with congruency nor with group.

Effect size. To control for age-related changes in the processing speed, interference and facilitation ratios were computed as suggested by Spieler et al. (1996).

The analysis of the interference ratios revealed a significant effect of group, $F(2, 45) = 3.65$, $p < .005$. Post hoc tests indicated a difference between youngs and old-olds only ($p < .05$). Groups differed also with regard to facilitation, $F(2, 45) = 4.81$, $p < .005$: the old-old group was the only one not showing facilitation.

Alzheimer's disease effect. The 3×2 ANOVA showed a significant congruency effect, $F(2, 30) = 10.81$, $p < .001$. Contrasts indicated that the incongruent condition was slower than both the neutral ($p < .005$) and the congruent one ($p < .001$); the two latter did not differ. The congruency $\times$ group interaction failed to reach significance, $F(2, 60) = 2.44$, $p = .09$. Thus, in both groups, the irrelevant variation in the physical size yielded interference but not facilitation. Again, inspection at the single-subject level indicated that six patients showed an advantage for the neutral condition compared to the congruent one, with the remaining individuals showing the opposite pattern.

The lack of facilitation seems to result from the variability among older adults and patients. Both groups included few individuals who showed an advantage for neutral compared to congruent trials. These subjects were disturbed by the irrelevant variation of the physical dimension, whether congruent or incongruent with the semantic dimension: neutral pairs were found easier, varying along a single relevant dimension.

Again, bilateral pairs were answered faster than unilateral pairs, $F(1, 30) = 12.77$, $p < .005$. This effect did not enter in any significant interaction.

Effect size. Neither the analysis of the interference ratios nor the analysis of the facilitation ratios detected differences between the groups.

Physical Task

Aging effect. A 3 × 3 ANOVA revealed reliable main effects of group, $F(2, 45) = 13.75$, $p < .001$ and congruency, $F(2, 90) = 11.30$, $p < .001$. Contrasts indicated an interference effect (incongruent trials were slower than both congruent and neutral ones, both $p < .001$) but no facilitation. No other interactions were significant.

Unilateral pairs were compared faster than bilateral pairs, $F(1, 45) = 10.30$, $p < .005$. The laterality × congruency interaction, $F(1, 45) = 6.34$, $p < .005$, indicated that the disadvantage for the incongruent condition was maximized in bilateral pairs.

Effect size. No reliable difference between the groups was detected in the ratios analyses.

Alzheimer's disease effect. A 2 × 3 ANOVA showed a significant group × congruency interaction, $F(2, 60) = 5.49$, $p < .01$. A reliable interference and a null facilitation affect characterized both groups' performance; yet, the congruency effect was maximized in the DAT group (DAT, $p < .05$; old-old, $p < .001$).

No laterality effect was found, while the interaction laterality × congruency was significant, $F(1, 30) = 5.50$, $p < .05$: although significant in all pairs, the congruency effect was maximized in the bilateral pairs.

Effect size. A reliable increase in interference in the DAT group compared to the old-old one was found, $F(1, 30) = 4.15$, $p < .05$. The groups did not differed with regard to facilitation.

Conclusions

The results indicate critical qualitative changes in elderly and DAT individual's performance that were not secondary to their general slower processing speed.

In the numerical task, the hypothesized selective attention breakdown in the older and the DAT groups is indicated by greater interference and by less facilitation. These subjects showed a disproportionate difficulty in ignoring irrelevant information, whether facilitating or not.

In line with previous studies, the physical task yielded an interference effect only. This effect has been shown to be constant across normal aging and to increase in the DAT group. Since interference indicates an inability to ignore numerical information, this suggests that automatic access to number magnitude may be preserved, at least in early stages of cognitive deterioration.

In both tasks, a standard laterality effect was found, showing an intact and efficient access to number magnitude representation. Thus, the basic ability to compare Arabic numerals seems relatively resistant to normal and pathological aging.

Finally, these results indicate that the number–Stroop paradigm may constitute a valid alternative to the standard–Stroop as a measure of selective attention in clinical practice.

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Letter and Number Writing in Agraphia: A Single-Case Study

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The gradual recovery of writing abilities of a patient whose processing of Arabic numerals and alphabetic script evolved differently over time is reported. Writing of multidigit numerals was achieved when writing of letters was nil. However, despite an initial advantage for numbers, the final examination disclosed fluent and correct writing of letters and words together with specific syntactic difficulties in complex Arabic numerals. The differential improvement for Arabic and alphabetic stimuli is partly explained in terms of different processing requirements rather than in terms of script-specific mechanisms only.

Introduction

It has been recently argued that alphabetic and Arabic scripts may be distinguished not only on the basis of their linguistic properties, i.e., in the former, symbols encode single phonemes while in the latter symbols encode single words, but also for engaging distinct processing mechanisms. Differences in the performance of alexic patients in reading alphabetic script and Arabic numerals have been considered evidence for script-dependent processing mechanisms (e.g., Cipolotti, 1995). Apparently, dissociations between alphabetic and Arabic scripts occur also in writing (e.g., Anderson, Damasio, & Damasio, 1990). Yet, part of this evidence, i.e., selective deficits in processing of Arabic numerals, seems more adequately explained in terms of the different processing requirements of the two scripts rather than in terms of script-specific mechanisms. In fact, though reading and writing of letters and single digits may well be directly compared, reading and writing of words and complex Arabic numerals clearly differ in their demands. Specifically, reading and writing of multidigit Arabic numerals or, in other words, mapping Arabic numerals into verbal numerals and vice versa, may not be accomplished by a term-by-term correspondence (e.g., one-hundred and four → 104 not 1004) but, rather, by decoding and combining specific place-value and lexical information. Thus, the existence of a double dissociation of the two scripts should be expected at the single unit level, i.e., in confronting letters and single digits processing only.

The selective preservation of Arabic numerals reading in alexic patients is a rather frequent phenomenon (e.g., Déjerine, 1892; Anderson et al., 1991). Yet, the reverse pattern of performance, impaired single-digit Arabic reading and preserved reading of letters and words, has been only recently documented (Cipolotti, Warrington, & Butterworth, 1995).

Difficulties in producing complex Arabic numerals in the context of otherwise normal writing abilities have been described in two case studies (Cipolotti, Butterworth, & Warrington, 1994; Noel & Seron, 1995). In both cases these difficulties were determined by defective syntactic processing.

Less documented is the writing of Arabic numerals in agraphic patients. The selective preservation of Arabic numerals production in severe agraphia where even single-letter writing was impossible was first documented by Zangwill (1954) and more recently by Anderson et al. (1991). Delazer and Denes (1998), instead, described a patient whose ability to combine numbers in well-formed two- and three-digit numerals contrasted with her extremely poor writing of words matched for length.

The present study investigates the gradual recovery of reading and writing abilities in a patient whose processing of Arabic numerals was better than his processing of alphabetic script. While this pattern of performance may be explained with a dissociation of the two scripts at the single unit level, at the level of complex numbers the dissociation is clearly due to different processing requirements.

Case Report

L.D. is a 65-year-old right-handed man who suffered from a CVA in October 1998. As a result he showed a right hemiparesis and a right hemianopsia. The CT scan showed an area of hypodensity in the left temporoparietal regions extending to deep subcortical structures. L.D.'s spontaneous speech was fluent but rich in circumlocutions in order to compensate word finding problems. The Aachener Aphasie Test (Italian version, Luzzatti, Willmes, & DeBleser, 1991) classified him as anomic aphasic. Verbal and digit span were normal. He was severely dyslexic and dysgraphic: reading aloud and writing of letters ($N = 21$) and single words ($N = 15$) were impossible. The deficit extended to Arabic numerals, where he failed to read and write even single digits. The only preserved written production was the automatic number sequence from one to nine and his signature. His ability to identify and match letters, visual patterns, and single Arabic digits visually presented in multiple choice tasks was perfect. His visual discrimination was normal. In the present study L.D.'s alexia and agraphia were investigated and the temporal evolution of these difficulties was evaluated over a period of 9 months.

Experimental Investigation

L.D.'s reading and writing of alphabetic stimuli and Arabic numerals were assessed in four testing sessions at 6, 8, 21, and 45 weeks after the CVA. The results are summarized in Table 1.

T1 (6 Weeks after Onset)

Reading. L.D.'s reading was severely impaired for all letters (0/21). Yet, he could recognize as familiar the letters of his name in whichever context he saw them. In contrast, he could read 8 out of 9 single-digit Arabic numerals: teens and 2-digit numerals were spelled out as sequence of single digits (e.g., 15 → ''one five'').

TABLE 1
L.D.'s Accuracy in Reading and Writing Tasks

	T1 correct/*n*		T2 correct/*n*		T3 Correct/*n*		T4 correct/*n*	
	Reading	Writing	Reading	Writing	Reading	Writing	Reading	Writing
Letters	—/21	—/21	—/21	—/21	19/21	21/21	21/21	21/21
Single words	—/15	—/15	—/15	—/15	—/15	14/15	—/15	15/15
Arabic numerals								
Single digit	8/9	9/9	9/9	9/9	9/9	9/9	9/9	9/9
Teens	—/9	—/5	4/9	5/5	3/9	5/5	4/9	5/5
Tens	—/6	—/4	2/6	4/4	2/6	4/4	2/6	4/4
Two-digit	—/10	—/5	1/10	5/5	1/10	5/5	1/10	5/5
Three-digit	—/20	—/15	3/20	13/15	3/20	14/15	3/20	15/15
Four-digit	—/30	—/23	3/30	6/23	2/30	9/23	2/30	15/23
Five-digit		—/23		3/23		2/23		8/23
	8/84	9/84	22/84	45/84	20/84	49/84	21/84	61/84

Writing. L.D. was completely unable to write on dictation single letters (0/21) or words (0/15). He complained he could not ''see'' them at all. Writing of Arabic numerals was preserved for single digits only (9/9); he refused to attempt writing of any longer stimuli. Although slow and labored, writing to copy was preserved: he was accurate with letters (12/12), Arabic numerals (10/10), and words (3/3).

Letter and number matching. L.D. was able to indicate which of two letters corresponded to a spoken stimulus (42/42). Similarly, he could identify the Arabic digit corresponding to a given spoken numeral (20/20).

Comprehension of spoken numerals. L.D. could easily tell the larger between two spoken numerals (two to five digits, 70/70) and produce the number that followed any given spoken numeral (''What comes next'' task, 40/40).

T2 (8 Weeks after Onset)

Reading. L.D.'s reading of any alphabetic stimuli was still impossible. By contrast, his reading of Arabic numerals was no longer limited to single digits (9/9) but he could read four out of nine teens and few multidigit numerals (9/66). Moreover, he never committed omissions: errors were mainly lexical [e.g., 530 → cinquecentonovanta (590), 79%) and, in few cases, mixed [e.g., 108 → sessantotto (68), 21%].

Writing. L.D.'s writing of alphabetic material was still nil. He mostly refused to attempt any writing, expressing the feeling that this ability was totally lost. By contrast, he wrote correctly single digits (9/9), teens (5/5), tens (4/4) and two-digit numbers (5/5), though with longer stimuli he often failed because of syntactic difficulties (22/61 correct). To further evaluate L.D.'s writing of Arabic numerals, additional three- to five-digit numerals were dictated ($N = 199$). He wrote correctly 75% of the three digits, 40% of four digits, and the 10% of five digits. Seventy-nine percent of the errors were syntactic, 11% were lexical, and 10% were mixed. The syntactic errors were highly systematic consisting of deletion of 0s, especially in the hundred and thousand structures [e.g., ''ottocentouno'' (801) → >81, Table 2).

Comprehension of Arabic and spoken numerals. His comprehension of numerals was preserved: he could accurately indicate the larger between pairs of spoken numerals (70/70) and of Arabic numerals (70/70) up to five digits.

TABLE 2
L.D.'s Writing of Arabic Numerals as a Function of the Length and the Structure of the Stimuli

Numerals	Arabic form	T2 correct/*n*	T4 correct/*n*	Most frequent type of error
Three-digits	No zero	13/15	15/15	Centosettantasei (176) → 173
	Internal zero	5/10	10/10	Novecentoquattro (904) → 94
	Final zero/s	12/15	15/15	Ottocentocinquanta (850) → 810
Four-digits	No zero	15/16	16/16	Millecentoventidue (1,122) → 1123
	Internal zero/s	21/31	2/31	Milleotto (1,008) → 18
	Final zero/s	14/18	16/18	Cinquemila (5,000) → 500
	Mixed	0/12	8/12	Seimilatrenta (6,030) → 630
Five-digits	No zero	1/4	4/4	Quarantaduemiladuecentotredici (42,213) → 42214
	Internal zero/s	2/38	14/38	Trentamilatrecentonove (30,309) → 339
	Final zero/s	1/19	11/19	Ventitremilacentoquaranta (23,140) → 2314
	Mixed	4/21	17/21	Quarantamilaventi (40,020) → 420

T3 (21 Weeks after Onset)

Reading. L.D.'s reading of alphabetical material was limited to single letters (19/21). Any attempt to read words failed with the patient giving up after several minutes. His reading of Arabic numerals was substantially unchanged from T2 (20/84): only single digits were error free.

Writing. L.D.'s writing of alphabetic stimuli improved significantly, as reflected by his writing of letters (21/21), single words (14/15), and nonwords (8/10). Errors consisted in substitution of single letters (e.g., radio → *p*adio). His writing of Arabic numerals was both quantitatively (33/84) and qualitatively (syntactic errors) similar to his performance in T2.

T4 (45 Weeks after Onset)

Reading. Reading of alphabetical stimuli was still limited to single letters (21/21); reading of words was clearly too difficult and frustrating the patient. L.D. read correctly single digits only (9/9); his accuracy dropped with two- to four-digit numerals (overall, 12/75), the majority of errors being of the lexical type (87%).

Writing. L.D.'s writing of letters (21/21), words (15/15), and short sentences (3/3, AAT) was accurate, fast, and clear. His performance on writing of Arabic numerals was clearly improved (61/84, 73%); thus the additional list used in T2 was dictated (Table 2). His performance was perfect with three-digit numerals, 79% correct with four digits, and 56% correct with five digits. All errors were syntactic: 93% of them consisted of deletion of 0s in the thousand structure [e.g., milledodici (1012) → 112], while the remaining consisted of insertion of zero in correspondence of the multiplier [e.g., settemilatrecentocinque (7305) → 70305]. Overall, these errors seem to reflect an inability to assigned place holder 0s in the Arabic form in correspondence to verbal multipliers.

Conclusions

The first evaluations of L.D.'s difficulties disclosed the isolated sparing of single-digit reading and writing in the context of a complete inability to process alphabetic material. These difficulties were not secondary to defective recognition and comprehension of visual and spoken stimuli or to apraxia (copy was possible). In analogy with the few previous reports, this pattern is thought to reflect a deficit in letter-form selection with sparing of number form (Zangwill, 1954).

At the level of complex stimuli L.D. wrote to dictation Arabic numerals when writing of letters was still impossible. Such a clear-cut dissociation has been reported only by Anderson et al. (1991). However, in the present investigation, this dissociation is further supported by the differential improvement in the two scripts over time. In fact, despite the initial advantage for numbers, the final examination disclosed fluent and correct writing of letters and words together with specific syntactic difficulties in writing complex Arabic numerals. The selective impairment in writing Arabic numerals in the context of normal alphabetic writing is here explained in terms of the specific processing requirements of the former: translating spoken verbal numerals into Arabic form requires mastery of specific transcoding rules and algorithms which are difficult to acquire (e.g., Power & Dal Martello, 1991) and sensitive to brain damage.

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Neuropsychological Impairments in the Syndromes of Schizophrenia: A Comparison between Different Dimensional Models

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This study investigates the associations between the different symptom dimensions of schizophrenia and neuropsychological performances. Globally, the results replicate previously described associations. The ''negative'' dimension correlates with impaired sustained attention and working memory, thus suggestive of dorsolateral frontal cortex dysfunction. ''Disorganization'' correlates with the ability to inhibit proactive interference, thus with ventromedial frontal dysfunction. The results also add support to the view that the ''psychotic'' dimension described in three-dimension models includes in fact two distinct dimensions, (1) ''hallucinations,'' here associated to episodic memory measures, and (2) ''delusions'', here associated to visuospatial attention, thus suggestive of mediotemporal and posterior neocortical dysfunction, respectively.

Introduction

The clinical heterogeneity is one of the most striking features of schizophrenia (Sz). Since the late 1980s, attempts at defining subtypes of Sz by factor analyses of symptoms have yielded to extract three distinct dimensions or syndromes (Liddle, 1987; Andreasen, Arndt, Alliger, et al. 1995): the negative dimension or ‘‘psychomotor poverty’’ (e.g., poverty of speech, decreased spontaneous movements, and blunting of affect), the ‘‘disorganization’’ (e.g., thought disorders, inappropriate affect, poverty of content of speech, and disorganized behavior), and the ‘‘psychotic’’ or ‘‘reality distortion’’ dimension (e.g., hallucinations and delusions and thought disorders).

Research has further demonstrated associations between each of these dimensions and specific neuropsychological measures (Liddle & Morris, 1991; Strauss, 1993; Norman, Malla, Morisson, et al., 1997). Psychomotor poverty correlates with deficits at card sorting and verbal fluency tests that are usually associated with lesions of the dorsolateral frontal cortex. Disorganization dimension is characterized by poor performances on tasks featuring the inhibition of interference. Similar impairments are observed following lesions in the ventromedial frontal cortex. Reality distortion is associated with deficits of verbal memory and delayed recognition, which are well documented in temporal lobe lesions.

Although the most influential model includes three dimensions (3-D), evidence has accumulated to support 4-D or 5-D models (Vasquez-Barquero, Lastra, Nunez, et al., 1996; Toomey, Kremen, Simpson, et al., 1997). In these models, hallucinations score separately from some types of delusions and from thought disorders. This distinction is supported by the observation that these symptoms occur independently in other diseases (e.g., epilepsy and delusional disorders). Furthermore, data suggest that hallucinations are associated with mediotemporal anomalies (Silbersweig, Stern, Frith, et al., 1995) whereas delusions and thought disorders are associated with anomalies in posterior neocortical areas (Liddle, Friston, & Frith 1992). Nevertheless, as a consequence of the preponderance of the 3-D model, none of the research investigating the neuropsychological correlates of symptom dimensions has attempted to take into account the heterogeneity of the positive dimension.

The objective of this study is to compare the patterns of association between different dimension models and performances on classical neuropsychological tests. These tests have been selected so as the performance on each one involves one of the brain regions of interest for the 3-D or 4-D models.

Method

Subjects

Twenty-seven patients (16 males; mean age 38.1 years) meeting the DSM-IV criteria for schizophrenia (paranoid, $n = 17$; disorganized, $n = 1$; residual, $n = 1$; unspecified, $n = 7$) signed an informed consent to participate in this study.

Symptom and Dimensional Ratings

An experienced M.D. trained with videotapes assessed patients’ symptomatology using the SAPS-SANS (Andreasen & Olsen, 1982). Dimension scores were calculated, for each patient, on the basis of four different models for which a detailed description is provided in the literature (Table 1). Two models include the three classical dimensions. The third model includes four dimensions, and the fourth model includes an additional dimension termed ‘disordered relating.’

TABLE 1

Characteristics of Dimension Models and Correspondances with Neuropsychological Data

Liddle & Morris (1991), SAPS–SANS, N = 43 chronic patients	Andreasen et al. (1995), SAPS–SANS N = 243 (169M) Sz and Szform dis. inpatients	Vasquez-Barquero et al. (1996), SAPS–SANS N = 86 (43M) first episode patients	Toomey et al. (1997), SAPS–SANS N = 549 (549M) chronic in- and outpatients	Neuropsychological correlates	Key component structure Liddle (1987); Liddle & Morris (1991); Strauss (1993); Norman et al. (1997)
Psychomotor poverty **5.2**	Negative **16.4**	Negative **18.7**	Diminished expression **6.1**	Verbal fluency, shifting sets Sustained attention	Dorsolateral frontal cortex
Disorganization **1.9**	Disorganized **8.8**	Disorganization **6.8**	Disorganization **4.4**	Proactive interference control Maintenance of info.	Ventromedial frontal cortex
Reality distortion **6.2**	Psychotic **11.2**	Nonparanoid **5.1**	Auditory hallucinations **3.3**	Episodic or explicit memory	Medial temporal lobe
		Paranoid **8.2**	Bizarre delusions **3.4**	Language, Semantic memory Visuospatial attention	Posterior cortex
			Disordered relatings **6.6**	Attention Vigilance	Diencephalic/reticular formation (?)

Neuropsychological Measures

Wisconsin Card Sorting Test (WCST). This test was originally developed to assess abstraction, executive function, and ability to shift cognitive sets. Performance on the WCST appears to be sensitive to frontal lobe dysfunction (Milner, 1963).

Continuous Performance Test—Identical Pairs (CPT). This test is used to assess impairments in sustained attention. The CPT has been found to be sensitive to dorsolateral frontal lobe and subcortical dysfunction (Cornblatt & Keilp, 1994)

Digit Span of the WMS-R (DS). This test is classically used to assess short-term memory and working memory. Performance on DS has been found to depend on dorsolateral frontal and parietal integrity (McCarthy & Warrington, 1990)

Canceling Test of Zazzo (CT). In this test the subject is required to check as quickly as possible target signs distributed among others on a sheet. It addresses the visuospatial attention process that depends on the integrity of posterior neocortical areas (Posner, Early, Reiman, et al. 1988).

Paired-Associates learning test of the WMS-R (PA). This test assesses the ability to learn and recall pairs of words, i.e., episodic memory. Performance on PA has been shown to be sensitive to mediotemporal dysfunction (McCarthy & Warrington, 1990).

Wickens' test for proactive interference and release of (WPI). This test was developed following Peterson's works (Wickens, 1963). The capacity to inhibit interference, assessed on the recall of the four first lists (all items of which belong to the same semantic category), depends on ventromedial frontal integrity. Failure to release interference, assessed with a fifth list (items from a category different of the other lists), can be taken as a kind of perseveration that depends on dorsolateral frontal lobe integrity (Fuster, 1980).

Correlation Analysis

Correlation analysis was carried out to detect significant associations between dimension scores and neuropsychological measures on each test. Spearman's correlations were used as a more conservative approach to avoid possible underestimation due to nonlinear relationships and because the SAPS–SANS scores are not continuous variables but ranks.

Results and Discussion

Globally, the results (Table 2) replicate those showing that performance on specific tests is associated with particular symptom dimensions. For the negative and the disorganized dimension, the correlation patterns are remarkably similar across models, hence supporting the great homogeneity and stability of these dimensions.

The *negative dimension* is primarily associated with impaired sustained attention and working memory, as measured by the CPT and DS. In two models, there is also a tendency for an association between the negative score and interference release when changing category at the WPI. All these impairments support the view that the dorsolateral frontal cortex is involved in the negative dimension. Surprisingly, although the performance on the WCST is usually associated with dorsolateral integrity, only the nonperseverative error score correlates with the negative dimension.

Disorganization is associated with recall scores at the second, third, and fourth lists of the WPI. Since these scores depend on the ability to maintain information against proactive interference from the preceding lists, the results support the association between disorganization and a dysfunction of the ventromedial frontal cortex.

TABLE 2

Correlation (Coefficients and *p* Values in Italics) between Neuropsychological Measures and Dimensions Scores as Defined in Four Different Models

	3-dimension model of Liddle and Morris (1991)			3-dimension model of Andreasen (1995)			4-dimension model of Vasquez-Barquero et al. (1996)				5-dimension model of Toomey et al. (1997)				
	Psychomotor poverty	Disorganized	Reality distortion	Negative	Disorganized	Psychotic	Negative	Disorganized	Positive paranoid	Positive non-paranoid	Diminished expression	Disorganized	Bizarre delusions	Auditory hallucination	Disordered relatings
Wisconsin Card Sorting Test (executive function-frontal lobe).															
% perseverative errors	.080	-.115	.129	-.128	.004	.144	-.117	.002	.259	.066	-.054	.063	.314	.145	-.165
	.691	*.567*	*.520*	*.525*	*.984*	*.473*	*.562*	*.992*	*.192*	*.743*	*.789*	*.755*	*.111*	*.471*	*.411*
% non-perseverative errors	.245	.520	-.129	.448	.558	-.106	.518	.435	-.088	-.015	.370	.472	.032	.028	.398
	.217	*.005*	*.520*	*.019*	*.003*	*.600*	*.006*	*.023*	*.663*	*.941*	*.057*	*.013*	*.874*	*.891*	*.040*
% Conceptual responses	-.198	-.337	.071	-.205	.446	.018	-.269	-.358	-.079	.003	-.209	-.435	-.232	-.083	-.148
	.322	*.086*	*.725*	*.304*	*.020*	*.929*	*.175*	*.067*	*.695*	*.987*	*.296*	*.023*	*.245*	*.681*	*.460*
Nb. Category completed	-.090	-.425	.056	-.117	-.454	-.001	-.175	-.383	-.074	.009	-.069	-.463	-.238	-.078	-.117
	.655	*.027*	*.781*	*.560*	*.017*	*.997*	*.384*	*.048*	*.713*	*.966*	*.734*	*.015*	*.233*	*.700*	*.561*
Nb. Trials/category	-.044	.627	-.223	.221	.651	-.183	.265	.628	-.017	-.245	.072	.731	.006	-.138	.291
	.826	*.000*	*.263*	*.268*	*.000*	*.362*	*.182*	*.000*	*.934*	*.219*	*.720*	*.000*	*.975*	*.491*	*.141*
Continuous Performance Test-Identical Pairs (sustained attention– dorso-lateral frontal lobe)															
% Hits	-.173	.009	.300	.049	-.287	.277	.015	-.278	.292	.280	-.111	-.110	.252	.330	.151
	.387	*.963*	*.129*	*.809*	*.147*	*.162*	*.940*	*.160*	*.139*	*.157*	*.581*	*.583*	*.204*	*.092*	*.452*
% false alarms	.453	.406	.131	.693	.526	-.024	.732	.415	-.046	.098	.628	.411	-.068	.185	.543
	.020	*.040*	*.523*	*.000*	*.006*	*.908*	*.000*	*.035*	*.825*	*.633*	*.001*	*.037*	*.741*	*.367*	*.004*
RT hits	-.380	-.177	.167	-.392	-.230	.281	-.393	-.180	.393	.130	-.373	-.124	.209	.066	-.278
	.090	*.443*	*.469*	*.079*	*.316*	*.217*	*.078*	*.434*	*.078*	*.574*	*.096*	*.592*	*.364*	*.776*	*.223*
RT false alarms	-.181	-.041	.212	-.273	.060	.173	-.273	.106	.205	.085	-.256	.007	-.013	.112	-.145
	.445	*.862*	*.369*	*.245*	*.800*	*.466*	*.244*	*.657*	*.385*	*.721*	*.275*	*.977*	*.956*	*.637*	*.542*
Digit Span of the WMS-R (working memory-dorso-lateral frontal and parietal lobe)															
Forward	.572	.272	.149	-.312	.021	.114	-.317	.096	.067	.115	.473	.181	.104	.122	-.065
	.002	*.171*	*.458*	*.113*	*.918*	*.572*	*.107*	*.635*	*.741*	*.569*	*.013*	*.367*	*.607*	*.544*	*.748*
Backward	.142	.041	-.021	.238	-.174	.116	.181	-.099	.180	.009	.176	-.037	.254	.016	.232
	.479	*.838*	*.915*	*.231*	*.384*	*.566*	*.366*	*.623*	*.369*	*.963*	*.380*	*.853*	*.202*	*.936*	*.243*
Canceling Test of Zazzo (visuo-spatial attention- posterior cortical areas)															
Scanning speed	-.257	-.018	.422	.116	-.034	.577	.102	-.009	.534	.514	-.070	.033	.609	.441	.331
	.195	*.930*	*.028*	*.565*	*.866*	*.002*	*.614*	*.964*	*.004*	*.006*	*.728*	*.870*	*.001*	*.021*	*.092*
Inexactitude index	.130	.166	.011	-.052	.229	-.119	.040	.089	-.218	.001	.008	.052	-.151	.097	-.090
	.517	*.408*	*.957*	*.797*	*.250*	*.553*	*.842*	*.659*	*.274*	*.998*	*.968*	*.795*	*.451*	*.631*	*.655*
Efficiency index	-.277	-.052	.380	.101	-.090	.548	.068	-.037	.531	.462	-.087	.011	.583	.377	.316
	.161	*.798*	*.051*	*.617*	*.654*	*.003*	*.735*	*.855*	*.004*	*.015*	*.664*	*.958*	*.001*	*.052*	*.108*
Paired-Associates Learning test of the WMS-R (episodic memory-anterior and medial temporal lobe)															
Easy pairs imm. recall	-.008	-.064	.015	-.064	-.046	.136	-.078	-.011	.082	.020	-.089	-.036	.115	-.085	-.050
	.967	*.747*	*.939*	*.746*	*.817*	*.489*	*.694*	*.956*	*.677*	*.921*	*.652*	*.856*	*.561*	*.667*	*.799*
Difficult pairs imm. recall	.002	.188	-.300	.011	.240	-.134	.008	.292	-.057	-.343	-.012	.237	-.254	-.409	-.034
	.991	*.337*	*.128*	*.955*	*.219*	*.496*	*.970*	*.131*	*.771*	*.074*	*.951*	*.225*	*.191*	*.031*	*.864*
Easy pairs delayed recall	.046	-.125	.001	.180	-.101	.107	.115	-.006	.141	.041	.187	.042	.202	-.032	.138
	.822	*.544*	*.995*	*.378*	*.624*	*.603*	*.577*	*.976*	*.493*	*.843*	*.360*	*.838*	*.321*	*.875*	*.503*
Difficult pairs delayed recall	-.028	.252	-.203	.113	.235	-.066	.128	.241	-.037	-.178	.070	.269	-.142	-.205	.092
	.891	*.214*	*.319*	*.583*	*.247*	*.749*	*.532*	*.236*	*.858*	*.384*	*.733*	*.184*	*.488*	*.315*	*.654*
Proactive Interference and Release (interference, sensitivity-ventro-medial frontal function)															
%recall 1st list	-.142	.246	-.199	.068	.110	-.144	.021	.212	-.118	-.119	.051	.281	-.051	-.117	.088
	.479	*.215*	*.319*	*.738*	*.584*	*.474*	*.917*	*.290*	*.559*	*.556*	*.801*	*.156*	*.801*	*.560*	*.663*
%recall 2nd list	.014	-.370	-.077	-.282	-.483	-.091	-.330	.426	-.098	-.053	-.079	.404	-.159	-.122	-.438
	.945	*.057*	*.702*	*.154*	*.011*	*.653*	*.093*	*.027*	*.627*	*.793*	*.695*	*.037*	*.428*	*.545*	*.022*
%recall 3rd list	-.139	.466	-.200	.110	.467	-.089	.101	.522	-.046	-.181	.006	.543	-.165	-.192	.146
	.490	*.014*	*.317*	*.586*	*.014*	*.661*	*.615*	*.005*	*.819*	*.367*	*.977*	*.003*	*.410*	*.338*	*.468*
%recall 4th list	-.235	-.397	.046	-.283	-.485	.034	-.335	-.416	-.032	.090	-.216	-.427	-.055	.053	-.205
	.249	*.045*	*.825*	*.161*	*.012*	*.867*	*.094*	*.035*	*.875*	*.660*	*.289*	*.030*	*.789*	*.797*	*.316*
%recall 5th list (category change)	-.360	-.126	-.106	-.244	-.223	-.016	-.306	-.087	.146	-.129	-.263	-.023	.071	-.159	-.149
	.071	*.540*	*.607*	*.229*	*.274*	*.937*	*.129*	*.674*	*.475*	*.529*	*.194*	*.911*	*.729*	*.438*	*.467*

In addition, there are associations between disorganization and WCST scores that are strong compared to those found in other studies (Norman, Malla, Morisson, et al., 1997). These associations concern measures (nonperseverative errors and number of trials/category) related to a disinhibition that leads the subject to privilege the speed of response over its accuracy, a characteristic often observed after ventromedial frontal lesions. This result supports the accumulating evidence that the WCST is a complex test which involves the frontal cortex as a whole rather than only its dorsolateral part (Seidman, Yurgelun-Todd, Kremen, et al., 1994).

Performance on some tests also supports the validity of 4-D or 5-D models that dissociate the psychotic dimension into two positive dimensions relying on distinct brain systems.

Hallucination or *positive nonparanoid dimension* is associated (significantly in one model and with a tendency in two others) with episodic memory measures (PA, difficult pairs) known to be sensitive to mediotemporal dysfunction. This observation agrees with the well-established association between hallucination and the mediotemporal structures in other diseases (e.g., epilepsy).

Delusion or *positive paranoid dimension* is strongly associated with measures of visuospatial attention (CT), thus supporting the idea that this dimension implies a dysfunction of the posterior cortex. It is however difficult to draw a firm conclusion from this result because the same measures also weakly correlate with hallucination and with the psychotic dimension in the 3-D models. In fact, this may reflect the role of mediotemporal lobe structures in spatial processing. Possibly, the use of tests addressing more specifically the posterior cortex will provide more selective patterns of associations.

Psychotic vs *reality distortion dimension* described in the two 3-D models appears to have distinct neuropsychological correlates. In Liddle's model, the reality distortion tends to be associated with visuospatial and episodic memory measures, similarly as in the hallucination dimension. In Andreasen's model, the psychotic dimension is associated only with visuospatial attention, in the same way as is delusion. Following the discussion above, this suggests that the reality distortion of Liddle's model is more related to the mediotemporal function (as emphasized in related publications), whereas the Andreasen's psychotic dimension is more related to the posterior cortical function.

This observation, which underlines the heterogeneity of the psychotic dimension in 3-D models, probably reflects differences in the items' composition of this dimension in the two models. These discrepancies can be partly associated with differences in the characteristics of the patient sample (see Table 1). There are also methodological differences in the way in which the factor analysis was conducted in the two studies. Andreasen's model is based on single-item scores whereas the Liddle's model includes the original SAPS subscales (i.e.< the sum of item scores).

Finally, *disordered relating dimension* correlates primarily with attention measures (CPT and CT), which supports its association with well-established pervasive impairment in attention possibly related to subcortical function (Table 1). Since attention impairment has been identified as one of the strongest predictors of the functional outcome of the patients (Green, 1996), this dimension could represent a general factor that restricts the social functioning of the patient.

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Left-Side Infant Holding: A Test of the Hemispheric Arousal–Attentional Hypothesis

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When asked to hold a young infant in their arms, most adults hold on the left side (Harris, 1997). In a prior study, we found the same bias when we asked adults merely to imagine holding an infant in their arms (Harris, Almerigi, & Kirsch, 1999). It has been hypothesized that the left-side bias is the product of right-hemisphere arousal accompanying certain aspects of the act, causing attention to be driven to the contralateral, or *left,* side of personal space. Left-side holding, whether actual or imagined, thus would be consistent with the direction to which the holder's attention has been endogenously directed. We tested this hypothesis by giving 250 college students the ''imagine-holding'' task and then, as an independent measure of lateralized hemispheric arousal, a 34-item Chimeric Faces Test (CFT). On the ''imagine'' test, a significant majority reported a left-side hold, and, on the CFT, left-side holders had a significantly stronger left-hemispace bias than right-side holders, although both left- and right-side holders had left-hemispace CFT biases. The results thus support the attentional–arousal hypothesis but indicate that other factors are contributing as well.

Introduction

From the time Salk (1961) reported finding that most mothers held their infants preferentially on the left side, the same bias has been confirmed many times for holding infants as well as infant dolls (Harris, 1997). The evidence suggests that the left-side hold cannot be solely to leave the right, normally dominant, hand free because left-handers also hold on the left, though usually by a smaller margin, and that it does not require femaleness, motherhood, or significant experience with infants because women with little or no experience also show it, as do men, although usually less strongly. Other proposed explanations have also fallen short, including the role of the maternal heart beat (Salk's hypothesis) and the infant's own normally head-to-right postural bias (Barnes, Cornwell, Fitzgerald, & Harris, 1985).

New evidence shows that the left-side bias does not even require holding a real infant (or doll). In a prior study, we (Harris, Almerigi, & Kirsch, 1999) asked 552 college students to ''imagine'' holding an infant. The result was a left-side bias comparable to that reported with real infants. Of the righthanders, 73% of the women and 68% of the men reported a left-side hold. Although the figure was higher for women than men, consistent with prior studies, the difference was not significant. For left-handers, the left-side effect was weaker, with the women's score dropping to 60% and to only 47% for men, with only the women's score different from chance. Like studies with real infants or dolls, these results thus cannot be squared with the motherhood or femaleness explanations inasmuch as nearly as many men as women reported a left-side hold. Like some prior studies, they also indicate a role for handedness and more strongly for men than women, but not as the *main* factor. Otherwise, the percentage of right-handers reporting a *left*-side hold should have been higher, as should the percentage of left-handers reporting a *right*-side hold.

If the left-side bias is not fully explainable by handedness, femaleness, or any of the other aforementioned variables, and if it occurs even on a test of imagination, then what else might be involved?

Hemispheric arousal–attentional hypothesis. For holding an infant (or even a doll), it has been hypothesized that the bias is a product of selective hemispheric arousal accompanying the act (Gordon, 1983; Harris, 1983, 1997; Harris et al., 1999; Turnbull & Lucas, 1996). The hypothesis supposes that the perception of faces, especially emotional faces, activates neural systems usually predominantly lateralized to the right hemisphere (e.g., Sergent, Ohta, & MacDonald, 1992), thereby driving attention to the contralateral, or *left,* side of personal space. Left-side holding thus would be in the direction to which the holder's attention has been endogenously directed by the act of engaging the infant. In our prior study (Harris et al., 1999), of course, the infant was only ''imagined,'' so, given the results, we had to posit that the image of oneself holding the infant arouses right-lateralized systems similar to those aroused by the actual act.

An advantage of the hemispheric-arousal hypothesis over others is that it may be better able to account for individual differences in strength of the left-side holding effect. For example, on divided visual field studies of the perception of tachistoscopically projected figures, including emotional faces, left-handers, as a group, usually show a weaker hemifield bias than right-handers but in the same, leftward, direction (e.g., Heller & Levy, 1981; Reuter-Lorenz, Givis, & Moscovitch, 1983). This would fit with the data on infant-holding, where left-handers either show a weaker left-side bias or, as in our prior imagine test, none at all, but in no case a significant right-side bias.

Individual differences also might reflect the nature of the task. For example, the often-found sex difference could square with evidence suggesting that for women, compared to men, the right hemisphere is more aroused for perception of emotional faces (e.g., Burton & Levy, 1989). Infants thus may engender stronger right-hemisphere arousal in women than in men, thereby initiating a stronger left-attentional bias and more left-side holding.

Beyond these possible sources of individual differences, at least one other may be at work. Levy, Heller, Banich, and Burton (1983) showed that behavioral tests of laterality, along with serving as an index of hemispheric specialization, are *simultaneously* sensitive to individual differences in characteristic patterns of asymmetric hemispheric arousal, reflected in magnitude and even direction of perceptual asymmetries. Holding an infant in one's arms or imagining oneself doing so are hardly ''standard'' measures of laterality, but if they trigger the same individually characteristic patterns of asymmetric hemispheric arousal as standard measures presumably do, it may explain why the percentage of left-holders is still less than the percentage of individuals in whom face-processing neural systems can be assumed to be predominantly right-lateralized.

Support for the hemispheric arousal–attention hypothesis would require showing a *direct* relation between side-of-holding and performance on an independent test of perceptual laterality. To date, we know of only two tests. In these tests, which compared doll holding with performance on line bisection and divided visual field tasks, the hypothesis was not supported (Lucas, Turnbull, & Kaplan-Solms, 1993; Turnbull & Lucas, 1996). At most, there was a trend in the line bisection task for left-side holders to bisect the lines farther to the left than right-side holders.

Current study. In the current study, we report a new test with a different measure of perceptual laterality: the free-viewing Chimeric Faces Test or CFT (Levy et al., 1983). In the CFT, pictures of faces with different expressions, typically smiling and neutral, are divided along the midline axis and reconstructed into chimeras, or composites, with the smile on one side and the neutral expression on the other. Each chimera then is flipped, creating a mirror-image reversal, and the subject is asked to judge which of the chimeric faces is happier.

The CFT is designed to take advantage of the hypothesized tendency for task-specific hemispheric specialization to bias attention toward one side of space relative to the other for information not initially restricted to one hemisphere. The rationale is that if one reliably chooses the face with the smile on a particular side, left or right, the contralateral hemisphere is assumed to be the more consistently engaged in the task.

Results typically show 65–70% of adults with a left visual-hemispace bias (e.g., Hoptman & Levy, 1988). That is, they judge the happier face to be the one whose hemismile is to their own left rather than right side, and, just as in divided visual-field studies, left-handers as a group usually show weaker biases than right-handers.

The percentage of adults with a left-hemispace CFT bias thus is roughly comparable to the percentage with a left-side holding bias on the imagine task. Based on the hemispheric arousal–attentional hypothesis, we therefore would predict a left-side CFT bias in left-side holders and a right-side CFT bias in right-side holders. This outcome not only would support the hypothesis; it would imply that the holding-side bias depends predominantly or even entirely on an arousal–attentional bias. Alternatively, finding that the left CFT bias is at least stronger in left-side than in right-side holders would support the hypothesis but would imply an important contribution for other variables as well.

Method

Subjects. The subjects were 250 university undergraduates, including 200 right-handers (39 men, 161 women) and 50 left-handers (21 men, 29 women). Handedness was assessed by self-report and confirmed by an eight-item questionnaire.

Chimeric faces task (CFT). The CFT included 34 pairs of happy-neutral chimeric faces, each pair on a separate page of a 34-page booklet. The two chimeras on each page were mirror images, placed one above the other, with the position counterbalanced across subjects. On each trial, subjects were asked to choose the chimera that is ''happier'' and to record their choice on an answer sheet.

Imagine-holding task. The ''Imagine-Holding'' task followed the CFT. The experimenter spoke the following instructions:

> ''Close your eyes and imagine that you are holding a young infant—say about three months of age—in your arms. Try to visualize the infant's face, its eyes, mouth, arms, and body. To help you imagine, put your arms in the position you would use to support the baby's head and body. Turn your head to the side so that you can look directly at the baby's face. [Allow 5 sec.] Now, on which side are you holding the baby's head—on your left side or on your right? Open your eyes and write left or right on your answer sheet.''

The subjects appeared to carry out the task without difficulty.

Results

CFT. On the CFT, an asymmetry score for each subject was calculated by dividing the number of left-face (smiling) choices by the total number of trials. Thus, the higher the score over 0.5, the stronger the left-hemispace bias; the lower the score below 0.5, the stronger the right-hemispace bias. Split-half reliability was 0.95.

The results are summarized in Table 1. The mean was .69 (SD = .27) for right-handers and .60 (SD = .32) for left-handers. The right-handers' score was significantly higher ($p = .037$), but both scores were beyond chance (right-handers, $p < .001$; left-handers, $p = .034$, two-tailed). The overall means for men and women were identical (= .67), but, in combination with handedness, were in reverse directions, with right-handed men scoring higher than left-handed men and with right-handed women scoring lower than left-handed women.

TABLE 1
CFT Means by Subject Subgroup

	Mean (SD)	*n*
Men		
Right-handers	0.72 (0.21)	39
Left-handers	0.57 (0.32)	21
Total	0.67 (0.26)	60
Women		
Right-handers	0.68 (0.28)	161
Left-handers	0.62 (0.32)	29
Total	0.67 (0.29)	190
Total		
Right-handers	0.69 (0.27)	200
Left-handers	0.60 (0.32)	50
Grand total	0.67 (0.28)	250

Note. CFT means also can be read as proportion of left side choices (of 34 items).

TABLE 2
Side of Cradle Means by Subject Subgroup

	Mean (SD)	*n*
Men		
Right-handers	0.74 (0.44)	39
Left-handers	0.57 (0.51)	21
Total	0.68 (0.47)	60
Women		
Right-handers	0.66 (0.47)	161
Left-handers	0.66 (0.48)	29
Total	0.66 (0.47)	190
Total		
Right-handers	0.68 (0.47)	200
Left-handers	0.62 (0.49)	50
Grand total	0.67 (0.47)	250

Note. Cradling means also can be read as proportion of left-side holds.

Imagine task. The results on the imagine-holding task are summarized in Table 2. Overall, 68% of the right-handers and 62% of the left-handers reported a left-side hold. This time, the right-handers' score was not significantly higher, but again both were beyond chance (right-handers, $p < .001$; left-handers, $p = .034$). The scores also were comparable for men and for women, although again, in combination with handedness, were in reverse directions, with 66% of the right-handed women ($p = .001$) reporting a left-side hold compared to 74% of the right-handed men ($p = .001$), whereas for left-handers, the figure for women was 66% ($p = .095$), and for men 57% ($p = .526$). Like the CFT scores, the results suggest that sex and handedness both contribute to the effect but in different ways.

Relation between performance on the two tasks. To find out whether hemispace bias on the CFT was related to side of holding, we calculated Pearson correlation coefficients for the two scores. For all 250 subjects, the means and correlation coefficients are listed in Table 3. The overall $r = .14$, significant at $p = .028$ (two tail). The correlation was in the same direction for all subgroups (right- and left-handed men and women), indicating a stronger left-hemispace CFT bias in left-side than in right-side holders, but was significant only for the right-handed men ($r = .34$, $p = .035$).

TABLE 3
Pearson Correlations between Responses on the CFT and the Imagine-holding Test

	Left hold		Right hold		Total	
	Mean (SD)	*n*	Mean (SD)	*n*	Pearson *r*	*n*
Men						
Right-handers	0.77 (0.18)	29	0.60 (0.25)	10	0.34*	39
Left-handers	0.62 (0.35)	12	0.51 (0.32)	9	0.16	21
Total	0.72 (0.25)	41	0.56 (0.27)	19	0.29*	60
Women						
Right-handers	0.70 (0.26)	107	0.65 (0.32)	54	0.08	161
Left-handers	0.65 (0.31)	19	0.56 (0.36)	10	0.14	29
Total	0.69 (0.27)	126	0.64 (0.32)	64	0.09	190
Total	0.70 (0.26)	167	0.62 (0.31)	83	0.14*	250

*$p < 0.05$, two-tailed.

Discussion

As in prior CFT studies, a significant majority of subjects showed a left-hemispace bias for choosing the ''happier'' face. Likewise, the percentage of subjects reporting a left-side hold was close to that in our prior ''imagine'' study (Harris et al., 1999) and in studies with real infants or dolls. This time, the percentage also was higher, though not significantly, for men than for women. The results also indicate a role for handedness and, again, more strongly for men than women but not as the *main* factor and for the same reason noted earlier.

Finally, in contrast to prior tests (Lucas et al., 1993; Turnbull & Lucas, 1996), the results provide a modicum of support for the hemispheric arousal–attentional hypothesis. In the group as a whole and in each sex by handedness subgroup, the left-hemispace CFT bias was stronger for left-holders than for right-holders, although the relation was significant only for right-handed men. In contrast, however, to the outcome that would constitute the strongest support for the hypothesis, namely, a reverse CFT bias in right-side holders, left-holders and right-holders alike had significant *left*-CFT biases, implying that other factors must be contributing to the effect. The correlation being significant only for right-handed men needs explanation. One possibility is that the men more than the women were primed by the CFT, which preceded the imagine-holding task. This also may explain why, in contrast to our own and other prior studies, proportionately more men than women were left-side holders. Further studies will be needed to put this possibility to direct test.

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Patterns of Apraxia Associated with the Production of Intransitive Limb Gestures Following Left and Right Hemisphere Stroke

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The model of apraxia proposed by Roy (1996) states that three patterns of apraxia should be observed across pantomime and imitation conditions. In the present analysis the frequency and severity of each pattern of apraxia were examined in a consecutive sample of left-(LHD) and right-hemisphere-damaged (RHD) patients during the production of intransitive limb gestures. The results indicated that a significant proportion of LHD and RHD patients were selectively impaired in formulating the ideational component of intransitive limb gestures.

Introduction

Apraxia is a disorder of skilled movement not caused by weakness, ataxia, akinesia, deafferentation, inattention to commands, or poor comprehension (Roy, 1996). Previous studies have noted that left, but not right, hemisphere damage (LHD, RHD) more frequently impairs the ability to perform a gesture in response to verbal command (pantomime). The nature of this deficit is thought to reflect the left hemisphere's specialization for the ideational stage of gesture production (Barbieri & De Renzi, 1988), indicating an impaired ability to access/select the representation of the gesture from semantic memory and/or the inability to generate the visual image associated with the gesture (Roy & Hall, 1992). Recent work by Roy et al. (in press) has questioned the notion that apraxia following LHD is exclusively related to an ideational deficit. Roy et al. examined the patterns of apraxia associated with pantomiming and imitating transitive limb gestures (see Roy, 1996, for a review). The first pattern is one in which performance is impaired to pantomime only (P_A I_{NA}), and the nature of the impairment is thought to reflect an impaired ideational stage of gesture production. The second pattern occurs when performance is impaired to imitation alone (P_{NA} I_A), reflecting an inability to analyze visual/gestural information, or in the translation of this information into movement. The final pattern, apraxic performance to both pantomime and imitation (P_A I_A) is thought to reflect an impaired executive stage of gesture production. Roy et al. noted that the proportion of patients who were apraxic to pantomime alone was relatively low (LHD = .05, RHD = .06), while a significantly greater proportion of LHD patients were apraxic to pantomime and imitation (LHD = .43, RHD = .23). These results suggest that apraxia following LHD damage is frequently attributed to an impaired executive stage of gesture production and not the result of a disruption to the ideational stage of gesture production, as indicated by previous research (i.e., Barbieri & De Renzi, 1988). A further question remaining in the apraxia research relates to the production of intransitive limb gestures in lateralized stroke patients. More recent apraxia research has focussed on the performance of transitive limb gestures (i.e., Roy et al., in press), which involve tool and/or objects, hence the frequency and severity of apraxia associated with the production of expressive/communicative intransitive limb gestures is less well documented. In the present investigation the patterns of apraxia proposed by Roy (1996) were examined in lateralized stroke patients during the pantomime and imitation of intransitive limb gestures.

Method

Participants

One-hundred and nineteen patients with a single unilateral lesion (LHD = 57, RHD = 62) and 20 age-matched control participants participated in this study. All participants were right-handed as indicated in their consent form or as indicated by consent from their proxy.

Gestural task. Participants were required to pantomime and imitate eight intransitive limb gestures. In the pantomime condition participants were asked to perform a familiar gesture to command (i.e., ''show me how to wave goodbye''). In the imitation condition the examiner demonstrated the gesture and the participant attempted to imitate the performance. The sample of gestures employed in the present task included nonrepetitive movements performed toward the body (salute) or away from the body (okay sign), and the other four were repetitive gestures performed toward (crazy) or away from the body (wave goodbye). Control participants used their left and right hand, with half beginning with their right, and stroke patients performed with their ipsilesional limb.

Performance scoring. The performance of each participant was videotaped and scored on the basis of five performance dimensions. The performance dimensions included: *orientation* of the hand, *action* (characteristics of hand movement through space), the *posture* of the hand, *plane* of movement of the hand, and *location* of the hand in space relative to the body. The videotaped performance of each participant was observed on five separate occasions, with separate dimensions scored per observation. Each dimension was rated on a three-point scale reflecting the degree of accuracy. Within each performance dimension three unique features were defined which allowed the observer to determine if the dimension should be rated as 2, 1, or 0. If each feature was present the performance was rated 2. If two features were present, performance was rated 1. A rating of 0 was given if one or less of the defined features were present. Each dimension was subsequently expressed as a percentage of the total possible score across the eight gestures. Finally, a *composite* score, representing overall movement accuracy (%) was derived from the scores across the five performance dimensions.

Data analysis. A two standard deviation rule permitted the identification of two categories of patients: apraxic and nonapraxic. A cutoff score based on the mean composite score of control participants was employed for the apraxic designation. A patient with a composite score greater than two standard deviations below the mean performance of control participants was classified as apraxic. Patients were classified separately for the pantomime and imitation conditions. Subsequently, patients were identified according to the pattern of apraxia demonstrated across pantomime and imitation conditions (see Roy, 1996).

Data related to the severity of apraxia were reflected in the five performance dimensions and the composite score. Using these measures, one set of analyses involved a univariate analysis of variance (ANOVA) procedure that focused on the composite score. For the five performance dimensions a multivariate analysis of variance (MANOVA, Pillai's Trace, $p < .05$) technique was employed.

Results

The frequency data revealed that the distribution of LHD and RHD patients did not differ across the three patterns of apraxia (see Table 1). The pattern occurring most frequently was that demonstrating impaired performance to pantomime alone (LHD = .38, RHD = .42). The pattern demonstrating apraxic performance to imitation alone occurred infrequently among LHD (.09) and RHD (.05) patients and the final pattern representing apraxic performance in both conditions revealed a marginally larger proportion of LHD patients (LHD = .30, RHD = .22), although this difference was not significant.

The benefit of employing the above classification system was that the severity of apraxia among the three apraxic categories could be compared with one another, thus providing a method for identifying the apraxic category with the most profound deficit. The first set of analyses involved comparing the pantomime performance of individuals classified as apraxic in both conditions, with those apraxic in pantomime alone (2 group (LHD, RHD) $\times$ 2 apraxic type (P_A I_{NA}, P_A I_{NA})). The composite score results indicated that those participants apraxic in both conditions were more impaired than those apraxic to pantomime alone, $F(1, 75) = 15.07$, $p < .001$; however, a group by apraxic classification interaction that approached significance, $F(1, 75) = 3.65$, $p < .06$, suggested that RHD patients classified as apraxic to pantomime and imitation were more impaired relative to their LHD counterparts, while LHD and RHD patients classified as apraxic to pantomime alone were equally impaired.

To address whether the apraxic deficit was related to a specific element of gesture production a 2 group (LHD, RHD) $\times$ 2 apraxic type (P_A I_{NA}, P_A I_{NA}) $\times$ 5 dimension (location, posture, action, plane, orientation) MANOVA was performed. These results revealed a main effect for apraxia classification, $F(1, 75) = 14.42$, $p < .001$, such that patients apraxic in both pantomime and imitation were more impaired than those apraxic to pantomime alone. Further, a group by dimension interaction, $F(4, 75) = 6.65$, $p < .001$, indicated that RHD patients were significantly less accurate than LHD patients on the dimensions of location, posture, and orientation. It was only the action dimension that LHD patients demonstrated a significant decrement in performance.

A second set of comparisons examined the imitation scores of patients apraxic in both conditions, with those apraxic on imitation alone. The composite score analysis failed to exhibit any significant effects or interactions ($F < 1$), while the analysis examining performance dimensions revealed a group by dimension interaction, $F(4, 35) = 4.15$, $p < .004$. Once again the group by dimension interaction demonstrated that the LHD patients were significantly impaired relative to the RHD group only on the action dimension.

TABLE 1
Frequency and Composite Score Accuracy Data for Patients with LHD or RHD in Each Apraxic Category

	LHD			RHD		
Apraxic pattern	Frequency (%)	Pantomime accuracy	Imitation accuracy	Frequency (%)	Pantomime accuracy	Imitation accuracy
P_{NA} I_{NA}	13 (23)	93.17	98.171	19 (31)	92.72	98.26
P_A I_{NA}	22 (38)	74.89	97.61	26 (42)	75.36	98.42
$P_{NA}I_A$	5 (9)	91.75	92.00	3 (5)	94.10	90.83
P_AI_A	17 (30)	69.01	88.89	14 (22)	58.21	89.51

Note. P, pantomime; I, imitation; NA, nonapraxic; A, apraxic.

Discussion

Focusing on the patterns of apraxia described by Roy (1996), the aim of the present investigation was to examine the frequency and severity of apraxia associated with the production of intransitive limb gestures in unilateral stroke patients. In the proceeding sections each pattern of apraxia will be discussed as it relates to understanding the mechanisms involved in apraxia.

Pantomime Dissociated from Imitation

The first pattern of apraxia represents an inability to pantomime but not imitate gestures. Previous research has suggested that this pattern of apraxia should provide the clearest evidence supporting the selective role of the left hemisphere in the ideational stage of gesture production (Barbieri & De Renzi, 1988). However, the present results do not support this position, as the proportion of LHD (.38) and RHD (.42) patients demonstrating this pattern was strikingly similar. Indeed, these results are incongruent with Barbieri and De Renzi (1988) who observed a higher frequency of LHD ($N = 12$) that RHD ($N = 2$) patients demonstrating this pattern. However, this discrepancy may be related to elements such as measurement sensitivity and the gestures employed in the apraxia battery. Barbieri and De Renzi did not focus on the details of movement execution and thus may have failed to detect subtle apraxic impairments associated with RHD. Moreover, previous research has typically failed to differentiate between transitive and intransitive gestures in their apraxia batteries; hence the large proportion of RHD patients demonstrating this pattern of apraxia suggests that the ideational component of intransitive limb gestures are subserved both by the left and both by right hemisphere.

Imitation Dissociated from Pantomime

The second pattern of apraxia is one in which apraxia is observed on imitation but not pantomime. A limited number of cases demonstrating this pattern have been reported (i.e., Roy et al., in press). The present results indicate that this form of apraxia occurs infrequently (LHD = 9% or $N = 5$; RHD = 5% or $N = 3$) but with approximately equal severity in the two stroke groups. While we are unable to determine the nature of the performance decrement from these data, our current work incorporates a gesture recognition/discrimination task. Performance on this task will enable us to determine whether this pattern arises from an impaired ability to analyze visual gestural information or in the translation of this information into movement.

Concurrent Apraxia on Pantomime and Imitation

The final pattern of apraxia reflects impaired performance to pantomime and imitation and is thought to arise due to deficits in the later or executive stage of gesture production. The occurrence of this pattern was only slightly greater in LHD patients (LHD = .30, RHD = .22); however, analysis of the performance dimensions indicated that LHD patients were particularly impaired on the action dimension, indicative of deficits in the planning or execution of movement trajectories. In conjunction, the frequency and severity data suggest that this pattern of apraxia following LHD may be linked to a specific element in motor programming/regulation. Our future work is aimed at extending the present results via kinematic analysis in order to examine the specific spatial–temporal elements impaired following LHD or RHD.

Conclusion

The present results provide insight into understanding the mechanisms involved in movement praxis. Specifically, the use of a multidimensional error notation system, the analysis of intransitive limb gestures in the present research, and the use of transitive limb gestures in our previous work (Roy et al., in press), have identified the involvement of the right hemisphere in praxis.

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Are Text and Tune of Familiar Songs Separable by Brain Damage?

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The recognition of text and tune in songs was examined in a music-agnosic patient and five matched controls. Listeners had to focus on one component of the song at a time (text or music) and had to decide whether the component was familiar or unfamiliar. Songs were either matched (i.e., an original familiar or an original unfamiliar song) or mismatched (a combination of a familiar component with an unfamiliar one). Normal listeners displayed response patterns that are congruent with those obtained previously in different experimental settings and which showed that text and tune are difficult to separate. Data collected in the patient, however, suggest some independence between text and music in songs. Moreover, the usual asymmetry in favor of text was much reduced when later verses were used. Overall, the results are interpreted as revealing strong association, not integration, between the musical and the verbal component of familiar songs.

A song is an artful arrangement of text and music. In many ways, the text and the tune of a song are separable from one another. For one thing, music and speech rely on completely different notation systems. In practice, however, the text and the music of a song are tightly bonded as they are most often, if not always, heard and performed in a combined form. Studies of memory for newly learned songs have shown a particular relationship between the text and the tune of a song: Recognition of any component of a song (be it the text or the tune) is *higher* if the text and the tune are placed in their original combination, than when placed in a new arrangement or when played alone (Serafine, Crowder, & Repp, 1984; Serafine, Davidson, Crowder, & Repp, 1986; Samson & Zatorre, 1991). This empirical result, termed the integration effect, has been interpreted as reflecting an integration between the text and the tune of a song. That is, the mental code for a song would not retain separate verbal and musical codes, but rather some unique, mixed, code.

Studies with brain-damaged populations have shown that amusic patients (i.e., patients who have difficulty processing music following brain insult) are able to make familiarity judgments when song texts are presented in a spoken form, while they are unable to do so when the tunes are sung on the syllable ''la'' (e.g., Peretz et al., 1994; Peretz, 1996; Griffiths et al., 1997). Thus, familiarity judgment on one component may be intact while it would be disrupted for the other component. These studies, however, have all assessed recognition of song components taken in isolation. The present study examined the recognition of song components in a brain-damaged patient when actual songs are presented.

We used a paradigm and materials different from the ones used in previous studies, which all involved novel songs in a recognition memory task imposing an important memory load on listeners (Serafine et al.,1984; 1986; Morrongiello & Roes, 1990; Samson & Zatorre, 1991; Crowder, Serafine, & Repp, 1990). For instance, the low recognition levels for tunes found in previous studies (sometimes at chance level, e.g., Serafine et al., 1984) indicate that the musical part of the songs did not enjoy a stable representation in the listeners' memory and that songs were liable to interference. A familiarity-decision task was used here with songs that were highly familiar or completely unknown (matched songs) or resulting from the combination of one component of a familiar song with one component of an unfamiliar song (mismatched songs). Listeners had to focus their attention on one component of the songs at a time (the text or the tune) and had to decide whether this component was familiar or not.

We predicted that if text and tune are separable in memory, the recognizability of each component should not be influenced by the presence of the other component. Therefore, performance for matched tunes should be the same as for mismatched tunes. In contrast, if text and tune are integrated in memory, performance level should be higher for matched than for mismatched songs.

Experiment 1

Method

Subjects. C.N. is a 40-year-old, right-handed nurse who had bilateral temporal lesions 10 years prior to the investigation. C.N.'s performance on the French version of the Boston Diagnostic Aphasia Examination (BDAE, Goodglass & Kaplan, 1972) showed no evidence of aphasia. Her only complaint was music-related activities. The recognition of tunes that were once familiar to her was at chance level. The data as well as a thorough case history of the patient have been published elsewhere (Peretz et al., 1994).

Matched controls.: Five women with no history of neurological or psychiatric disease served as C.N.'s controls. Like C.N., they were all nurses working in hospitals (mean age 39.6 years) without formal music education.

Materials. Ten pairs of song excerpts generated the 40 stimuli used in this experiment. Ten song excerpts were highly familiar and known to have been acquired in childhood (Peretz, Babaï, Lussier, Hébert, & Gagnon, 1995). Ten additional song excerpts were drawn from two collections of folk songs comparable in style to the familiar ones, but were unfamiliar (Berthier, 1979; Sabatier & Sabatier, 1987). Each unfamiliar song was selected so as to be interchangeable in text and tune with one familiar song. Care was taken to obtain the best fit in pause and accent locations between the musical parts and the text in the mismatched songs.

Each pair of excerpts generated four different types of songs: two matched songs, that is, a familiar and an unfamiliar song, and two mismatched songs, that is, a familiar text coupled with an unfamiliar tune, and a familiar tune coupled with an unfamiliar text. The procedure is shown in Fig. 1.

These 40 songs were sung by the first author without musical accompaniment and digitally recorded on a DAT Casio. Songs from the matched and mismatched sets were similar in length (means = 4.85 and 4.74 s for matched and mismatched songs, respectively, $t(38) = 0.20$, $p > .05$). These recordings were stored on the hard disk of a MacIntosh IIFX and transmitted directly from the hard disk to the subject via a Digidesign Digital interface amplifier and Maico headphones. Two random orders were determined and the final products were presented to the subjects by using the Experimenter program (Altmann, Wathanasin, Birkett, & Russell, 1992).

Procedure. The same 40 songs served as stimuli in two conditions, which differed only by the instructions given to the subjects. In one condition, C.N., and her matched controls were instructed to judge whether the text of the songs was known or unknown while ignoring the tune (the ‘‘Text’’ condition). In the other condition, they were required to focus on tunes while ignoring the text (the ‘‘Tune’’ condition). Subjects were tested individually in a session lasting about 15 min. They had to respond as quickly and as accurately as possible, by pressing one of the two keys of a response box, depending on whether their response was ‘‘known’’ or ‘‘unknown.’’ The subjects had 4 s to key in their response after the end of the trial, and the next trial began after a 2-s pause. No feedback was provided. C.N. and her matched controls received both instructions twice, thus amounting to four different sessions. For controls, the orders of presentation of the conditions were counterbalanced across subjects. C.N. received conditions following an ABBA design.

Pretests. Before the experimental sessions, C.N. and her matched controls were tested on two separate pretests to examine their performance when each component of the to-be-presented songs (i.e., the text and the music) was heard separately. In the first pretest, all familiar and unfamiliar songs which were to be used in Experiment 1 ($n = 20$) were sung on the syllable ‘‘la.’’ In the second pretest, the text line corresponding to the text of each of these same familiar and unfamiliar songs was spoken by the same person. Subjects were asked to judge whether the tunes (pretest 1) and the text (pretest 2) were known or unknown. Results are shown in Table 1.

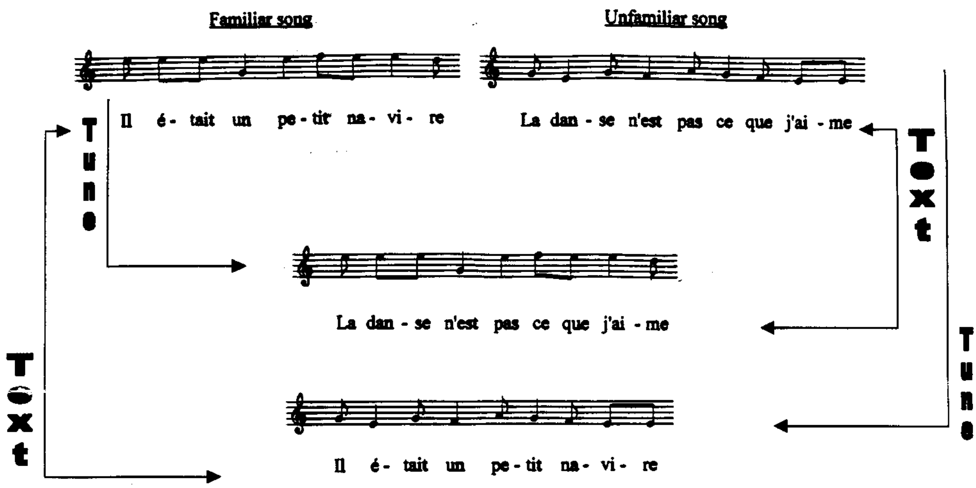

FIG. 1. Example of the mismatching procedure used. A familiar song and an unfamiliar song generated two additional types of songs by mismatching the text of the familiar song with the tune of the unfamiliar song and by mismatching the tune of the familiar song with the text of the unfamiliar song.

TABLE 1
Recognition Scores Obtained in the Pretests (Isolated Components) and in Experiments 1 and 2 for C.N. and Her Matched Controls

	First verse				Second verse			
	Text		Tune		Text		Tune	
Song type	C.N.	Controls	C.N.	Controls	C.N.	Controls	C.N.	Controls
Matched	.85	.98	—	.89	.80	.94	—	.80
Mismatched	.95	.93	—	.65	.70	.76	—	.74
Mean	*.90*	*.96*	*	*.77*	*.75*	*.85*	*	*.77*
Isolated	.80	1.0	*	.80 (.50–1.0)	.70	.82 (.50–1.0)	—	—

**not different from chance level.*

Results and Comments

The average proportion of hits (i.e., the proportion of ‘known’ responses when the component under focus is indeed familiar) and the proportion of false alarms (i.e., the proportion of known responses when the component under focus is unfamiliar) were calculated for the four types of songs, averaged across subjects and order of presentation[1]. The recognition score (proportions of hits minus the proportion of false alarms) for matched controls were entered in an ANOVA with Items as the random factor, taking Instructions (focus on Text/Tune) and Song type (Matched/Mismatched) as the within-items factors. Since C.N. was performing at chance level under the ‘‘Tune’’ instruction, obtaining 49 correct responses of 80 ($Z = 1.90$, $p >$ .05 by a binomial test), her data in this condition were not examined further. Only her data in the ‘‘Text’’ condition, on which her performance was excellent (76/80), were so analyzed.

Table 1 displays the scores for Experiment 1 (left panel) for the two Instructions and the two Song types for C.N. and her matched controls.

For Matched controls, the effect of Song type was significant, with $F(1, 9) = 13.30$, $Mse = .40$, $p < .006$. The effect of Instruction was also significant, with better performance under the Text instruction than the Tune instruction, $F(1, 9) = 19.22$, $Mse = .45$, $p < .003$. The interaction between Instructions and Song type was also significant, $F(1, 9) = 6.64$, $Mse = .34$, $p < .031$.

Because of the very high performance levels in the Text condition, the difference between Matched and Mismatched songs just fell short of significance $t(9) = 2.24$, $p = .052$, whereas this difference was significant under the Tune instructions, $t(9) = 3.27$, $p < .05$, for paired t tests. These results show that in normal subjects, it is very difficult to separate the text and the tune of a song. Even when a judgment of familiarity must be made on only one component of a song, the other component cannot be ignored and influences the judgment. A component of a song, be it the text or the tune, is easier to judge as being familiar or unfamiliar when it is accompanied with its original companion.

Overall, C.N. performed in the normal range for text recognition with an overall mean of .90 (range of controls .70–1.00). The advantage for Mismatched over Matched

[1] A preliminary analysis revealed a test/retest effect in the data of C.N.’s matched controls. The second presentation yielded lower scores than the first order of presentation (proportions obtained were .90 and .83 for order 1 and 2, respectively). As this is more likely to be due to a fatigue effect than to a learning effect, the data were collapsed across the two orders.

songs was not significant, $t(9) = 0.43, p > .05$, for a paired t test. Unlike normal listeners, however, C.N. could ignore the tune while she made a familiarity judgment on the text of a song. This lack of influence of the tune in C.N.'s judgments indicates that there is a fair level of separability between the text and the tune of a song.

Experiment 2

In Experiment 1, the lyrics of the song may be represented both in song memory and in ''titles'' memory since the first verse of the song often corresponds to its title (e.g., Frère Jacques). In order to test song memory, texts from later verses of the songs were considered here, but were sung on the same tune as in Experiment 1, hence allowing variance of the strength of the representation for words while keeping the tune constant.

Method

C.N. and her five controls participated in Experiment 2. The same 10 pairs of songs served for this experiment. Only, the text was changed so that it did not correspond to the first line of the songs, but was drawn from later verses. The only restrictions were that the text should not correspond to the tune title and the music should remain the same as in Experiment 1. The procedure was identical as in Experiment 1, except that subjects received each instruction only once.

Pretest. C.N. and her matched controls were again presented with a pretest to examine their performance when the text line of the songs was heard separately in a spoken form. Results are summarized in Table 1.

Results and Comments

The recognition scores were calculated in the same way as in Experiment 1. C.N. performed again at chance level under the ''Tune' instruction, obtaining 23 correct responses of 40 ($Z = 0.79$, $p > .05$ by a binomial test), a finding consistent with that of Experiment 1 since the musical part of the songs in both experiments was the same. Table 1 displays the scores for Experiment 2 (right panel) for the two Instructions and the two Song types for C.N. and her matched controls.

In Matched controls, the effect of Song type was again highly significant, $F(1, 9) = 7.36$, $MSe = .020$, $p < .03$. Recognition of Text was still higher than Tune, but not statistically so, $F(1, 9) = 1.38$, $MSe = .05$, $p > .27$. The effect of Song type was found reliable under both instructions since the interaction between Song type and Instruction was not significant.

As for her matched controls, C.N. performed lower in this condition than in Experiment 1, but she performed within the normal range with an overall mean of .75 (range of controls .40–1.0). The effect of Song type was not significant, $t(9) = 1.0$, $p > .05$, for a paired t test.

The results are consistent with the view that the text and the tune of a song are difficult to separate in normal subjects. Even when a judgment of familiarity must be made on only one component of a song, the other component cannot be ignored and influences the judgment. A component of a song, be it the text or the tune, is easier to judge as being familiar or unfamiliar when it is accompanied with its original companion. The usual superiority effect of the text over the tune can be lowered by using verses that are less familiar, without changing the advantage for original over nonoriginal songs.

In contrast with normals, C.N. could ignore the tune while she made a familiarity judgment on the text of a song. The lack of influence of the tune in C.N.'s judgments indicates that there is a fair level of separability between the text and the tune of a song.

General Discussion

These two experiments both replicate and extend previous findings on the organization of text and tune in memory for songs. In support of past studies, we found that in a normal brain the text and the tune of songs are difficult to separate: It was easier to judge the familiarity of the text or the tune of a song when the song was original than when it was not. We showed here that this result is neither material or task bound, but rather holds across paradigms, language, and level of familiarity with the songs presented.

Our study also extends previous findings by showing that the usual superiority of text over tune can be lowered without affecting the ease of judging the components of matched over mismatched songs. In Experiment 2, we succeeded to make the text less recognizable than the corresponding tune, by selecting less familiar verses of the songs. In all previous studies (Serafine et al., 1984, 1986; Crowder et al., 1990; Morrongiello & Roes, 1990; Samson & Zatorre, 1991) as well as in our Experiment 1, the text was systematically better recognized than the accompanying tune. This systematic asymmetry in saliency for the text over the tune may account for a large part of the association effects observed previously. The fact that we could decrease the difference here without canceling the superior recognition performance exhibited for the tune sung with its original, but less salient, text demonstrates that the advantage of matched over mismatched songs does not simply rely on the text of songs. It is noteworthy, however, that across conditions, the tune contributes much less to the recognition of the text that the text contributes to the recognition of the tune. In the latter case, the text substantially aids tune recognition. This observation may be related to the functional role of music in verbal recall, as used in oral traditions. Typically, songs consist of many verses organized around a few melodic lines. The music serves as a sort of mnemonic for text recall (Gingold & Abravanel, 1987; Hyman & Rubin, 1990; Wallace, 1994; Peretz et al., 1995).

In normal listeners, it was easy to elicit behavior that is compatible with a view that suggests an integration between text and tune. The neuropsychological data, however, suggest that this relationship might be one of association, rather than integration. The data collected in our brain-damaged patient who had difficulty in processing the musical part of the songs suggest an association, not an integration, between the two components of a song. Our patient was able to decide whether the text of the songs was familiar or not, and her performance was not significantly influenced by the presence of the tune. If text and tune were integrated in memory, this familiarity decision should have suffered from the presence of an irrelevant tune. Yet, this pattern was not obtained, suggesting that text and tune are related by association links, each tapping on independent processing resources. These results converge with the existing neuropsychological literature that suggests separability between text and tune in memory recognition (Peretz et al., 1994; Peretz, 1996; Griffiths et al., 1997). It should be noted, however, that the opposite pattern of dissociation between text and tune in songs remains to be reported. That is, a patient with impaired processing of the verbal component of songs and intact processing of music, who would be able to judge the familiarity of the tune without any influence of the text, has, to our knowledge, never been described. Such a case, combined with C.N., would provide an instance of double dissociation and hence would provide stronger evidence for the autonomy of text and tune in songs.

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The Role of Nasals in Reading: A Normative Study in French

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Dual-route models of reading assume that reading can be done in two ways. A most common lexical route, on the one hand, allows regular and irregular words to be read while a second sublexical route allows nonwords and novel words to be read. A graphemic processing stage in sublexical reading is assumed to assemble the individual letters of a word or a nonword into multiletter graphemes prior to grapheme–phoneme conversion. The purpose of this study was to determine whether vowel/nasal clusters required as much time to be processed as vowel/vowel and consonant/consonant clusters in sublexical nonword reading in French. Results indicate that nonwords that contain vowel/nasal clusters are read significantly faster than nonwords comprising vowel/vowel and consonant/consonant clusters. Furthermore, nonwords that contain single-letter graphemes are read significantly faster than nonwords comprising vowel/nasal clusters and nonwords comprising vowel/vowel and consonant/consonant clusters. These results taken as a whole support the idea that nasals act as diacritic marks rather than being processed by means of a graphemic parsing procedure.

Introduction

According to cognitive neuropsychological dual-route models of reading, there exist two functionally independent processes of reading. First of all, lexical processing involves a direct access to a word-form system in which whole word visual and phonological representations are stored. Second, sublexical processing involves subword analysis: Letters and graphemes are converted into phonemes and syllables by means of specific subword conversion rules. Phonemes are then assembled into an assembled phonological form. Generally, sublexical processing allows novel regular words and nonwords to be read while lexical processing allows words which contain irregular pronunciations to be read (Lecours, 1996).

Dual-route models are justified by the existence of specific lexical and sublexical impairments. Phonological dyslexics, for example, demonstrate a specific impairment in reading nonwords and regular novel words, whereas reading irregular words remains relatively intact (Desrouesné & Beauvois, 1979; Funnel, 1983; Coltheart, 1996). In surface dyslexia, however, the inverse profile is observed: Individuals show a specific deficit in reading irregular words while subword analysis does not appear to be impaired (Behrmann & Bub, 1992). This double dissociation between the lexical and sublexical routes is not as clear cut as it appears to be however, since both of these types of reading impairments are often accompanied with other related deficits. Furthermore, dual-route theory is also supported by the existence of specific stages corresponding respectively to sublexical and lexical reading, in learning to read irregular alphabetic codes such as French and English (Coltheart, 1987). For example, in the second year of school, children specifically learn to match single-letter and multiletter graphemes to their phonemes, thus favoring sublexical analysis. In the following year, however, children learn to match the global orthographic forms of words (usually short and frequent) to their spoken form. Gradually, children complete a transition toward a more global and efficient strategy of reading. The transition from one stage to another seems to be essential to a normal reading progression (Vellutino and Scanlon, 1991).

The present study is interested in specific cognitive components inherent to sublexical reading. Recent dual-route models assume that in sublexical processing (in this case nonword reading), individuals letters can be matched directly to their corresponding phonemes (e.g. TARCOL, in French) or can also be assembled into multiletter graphemes that contain a single equivalent phonemic representation (e.g. *CH*ARB*AU*, in French) (Lecours, 1996; see Fig. 1). Since assembling letters into complex graphemes requires an additional sequential processing stage, nonwords that contain complex graphemes are read significantly slower than nonwords that contain single-letter graphemes. Let us note at this point that a phoneme corresponds to the phonological equivalent form of a written grapheme. In French, complex graphemes consist on the one hand of consonant clusters (e.g., CH, PH) and vowel clusters (e.g., AU, EAU, OU), while on the other hand they consist of vowel/nasal clusters (e.g., ON, OM, AN). In the first and second instances, the pronunciation of the individual letters comprised in a complex grapheme is different from that of its assembled pronunciation (e.g., a $>$ [a], u $>$ [y], au $>$ [o]). In the case of vowel/nasal clusters,

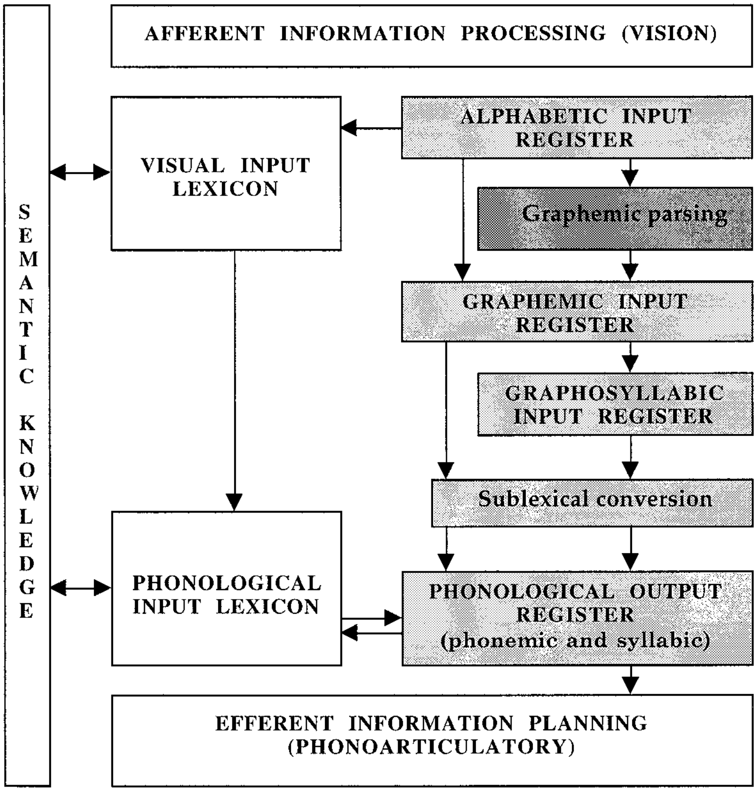

FIG. 1. Schematic representation of a recent neuropsychological model of reading aloud (Lecours, 1996). The various components of the sublexical route appear in gray. Sublexical graphemic parsing appears in dark gray. Take note, however, that initial perceptual processes (*afferent information processing*), final articulatory programming (*efferent information planning*), and individual letter recognition (*alphabetic input register*) are shared by both the lexical and the sublexical routes.

however, the nasal only slightly modifies the pronunciation of the vowel that precedes it (e.g., a > [a], n > [n], an > [ã]). We thus assume that nasals play the role of diacritic marks, in the same way that do accents in French (e > [′], é > [e]). We also assume that this procedure is less demanding in terms of cognitive processing than reading complex graphemes containing vowel or consonant combinations. Thus, nonwords comprising vowel/nasal clusters should be read significantly faster than nonwords comprising only vowel or only consonant clusters. Also, nonwords containing vowel/nasal combinations should require the same reaction times (RTs) to be read as nonwords containing single-letter graphemes.

Method

Subjects and material. Thirty French-speaking undergraduate students served as subjects. All of them were right-handed, with no personal or family history of dyslexia or any neurological or psychiatric impairments.

The stimuli consisted of sixty bisyllabic six-letter legal and pronounceable nonwords in French. The nonwords were presented for reading aloud singly in pseudorandomized order. The 20 nonwords of List 1 were composed of single-letter graphemes (e.g., TARCAL), the 20 nonwords of List 2 were composed of vowel/nasal multiletter graphemes (e.g. P*AN*F*ON*), and the 20 nonwords of List 3 were composed of multiletter vowel/vowel and consonant/consonant graphemes (e.g., *PH*IT*AI*).

Sixty distracter nonwords were added to the randomization in order to conceal the nature of the experiment.

The stimuli of each list were matched for sublexical bigram frequency and onset characteristics. A grapheme was defined as being the written equivalent form of a phoneme. Initial, middle, and final sublexical frequencies were taken from the Constant and Radeau (1988) frequency tables for the French language. There is no existing data on phoneme frequency, but we assumed that there was a close match between sublexical graphemic and phonemic frequencies.

Procedure. The subjects were asked to read nonwords which appeared one by one on a computer screen as quickly and as accurately as possible (the subject performed a practice run of 10 stimuli). The computer recorded the latency of each response (in ms). Reaction times were measured in terms of the time elapsed between the beginning of the presentation of the stimulus and the first sound pronounced by the subject. Subjects were tested individually.

Results

The results of a one-tailed t test for unpaired samples indicate that the reaction times were significantly slower for nonwords that contained vowel/vowel and consonant/consonant clusters (List 3) than for nonwords that contained vowel/nasal clusters (List 2) ($t = -3.19$, $p < .0017$ (29 *d.f.*)). Mean RTs for List 2 was 766.28 ms (SD = 149.18 ms) and 797.89 ms for List 3 (SD 170.95 ms). The difference in RTs between the two lists was 31.61 ms (see Fig. 2).

The results of a one-tailed -test for unpaired samples indicate that the reaction times were significantly slower for nonwords that contained vowel/nasal clusters (List 2) than for nonwords that contained single-letter graphemes (List 3) ($t = -4.60$, $p <$ .000038 (29 *d.f.*)). Mean RTs for List 2 were 766.28 ms (SD 149.18 ms) and 722.81 ms for List 1 (SD 145.37 ms). The difference in RTs between the two lists was 43.42 ms (see Fig. 2).

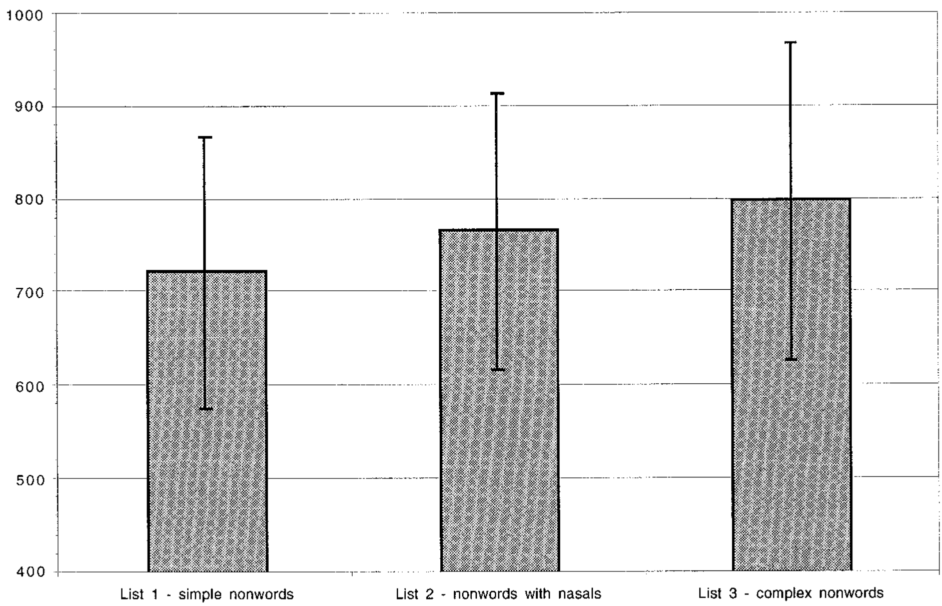

FIG. 2. Reaction times (RTs) and standard deviations (SDs), expressed in milliseconds, for nonwords comprising single-letter graphemes (simple nonwords), nonwords comprising vowel/nasal combinations, and nonwords comprising vowel/vowel and consonant/consonant clusters (complex nonwords).

The results of a one-tailed *t* test for unpaired samples indicate that the reaction times were significantly faster for nonwords that contained single-letter graphemes (List 1) than for nonwords that contained vowel/vowel and consonant/consonant clusters (List 3) ($t = -4.83$, $p < .00001$ (29 *d.f.*)). Mean RTs for List 1 were 722.80 ms (SD 145.37 ms) and 797.89 ms for List 3 (SD 170.95 ms). The difference in RTs between the two lists was 75.09 ms (see Fig. 2).

Discussion

Nonwords that contained graphemes with vowel/nasal combinations were read significantly faster than nonwords that contained vowel/vowel and consonant/consonant combinations. Furthermore, nonwords that contained graphemes with vowel/nasal combinations were read significantly slower than nonwords that contained single-letter graphemes. These results taken as a whole support the idea that nasals act as diacritic marks rather than being processed by means of a graphemic parsing procedure (i.e., vowel/vowel and consonant/consonant complex graphemes).

It thus seems that nasals only modify the pronunciation of the vowels that precede them rather than producing a phoneme whose pronunciation is different from that of its individual letters. It is therefore reasonable to assume, in the framework of cognitive dual-route models of reading, that the mechanism involved in reading vowel/nasal clusters in French is different from that of graphemic parsing. Instead, it is more plausible to assume that nasals act as diacritic marks (e.g., a > [a], n > [n], an > [ã]), in the same way as do accents in the French language (e.g. e > [ʹ], é > [e]). This idea is supported by the reaction times obtained in the present study. Furthermore, it is interesting that single-letter graphemes are processed significantly faster than vowel/nasal graphemes in nonword reading, considering that both lists were matched for sublexical frequency. This suggests that there might be an intermediate processing stage for processing diacritics (nasals in this case) in the sublexical route, for instance, between the individual letter analysis stage and the graphemic processing stage.

These results as a whole give us some insights on the relatively undocumented sublexical mechanisms of reading. They confirm the notion that sublexical reading proceeds by way of a sequential processing mechanism (all lists were matched for sublexical frequency and onset characteristics), as expressed by the very significant differences in reaction times. In conclusion, we stress the importance of using normal subjects in studying the cognitive processes inherent to reading, in parallel with neuropathological and neuropsychological data.

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