Oral Language Deficits in Dyslexic Children: Weaknesses in Working Memory and Verbal Planning

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This paper focuses on the relationships among language processing (word- and sentence-level), working memory, and verbal/nonverbal linguistic output. The study examined oral language abilities in a group of 26 French-speaking dyslexic children, compared to two control groups (26 normally developing age-matched children and 26 normally developing younger children). The experimental procedure consisted of tasks involving auditory memory skills (digit span, unfamiliar word repetition, sentence repetition), word retrieval (with semantic, phonological and grammatical criteria), and sentence processing (with verbal and act-out production). The major findings reveal that (a) compared with their age-mates, the dyslexic children exhibited a significant deficit affecting all tasks; and (b) the dyslexic children and the younger controls performed similarly on several tasks. The results are consistent with the processing limitation hypothesis and suggest that the core deficit is the formulation of cognitive plans from auditory input to verbal output.

INTRODUCTION

Previous studies have established that dyslexic children are deficient in several areas of language functioning. They exhibit difficulties with (a) segmentation and manipulation of segments, (b) object naming, (c) phonetic perception, (d) verbal working memory, and (e) comprehension of complex spoken sentences (Liberman & Shankweiler, 1985; Katz, 1986; Hoien, 1989; Perfetti, 1989; Snowling, 1989; Kamhi, 1992; Catts, 1993; Plaza, 1997; Plaza & Guitton, 1997; Swann & Goswami, 1997). The relationship between such language impairments and the reading disorder itself is a matter of controversy. According to *the co-occurrence hypothesis,* the links between dyslexia and oral language impairment are not direct; failure to develop reading ability co-occurs with a general lag in language acquisition (Byrne, 1981). In that sense, the reading disorder is not a unitary disorder; rather, it appears to be multiply determined (Stein et al., 1984). The *structural hypothesis* posits a closer relationship between language impairment and reading disorder. Scarborough, for example, hypothesized that a general mechanism may underlie the deficiencies exhibited by dyslexic children in both verbal and written language. Such difficulties could relate to the acquisition and use of the rules that underlie the various combinations of phonemes and function words which, as abstract formal elements, are difficult to learn and vulnerable to impairment (Scarborough, 1990). The *processing limitation hypothesis* attempts to tie together all of the problems experienced by dyslexics, viewing them as derived from the inefficient processing of phonological structures. Dyslexic children are assumed to master all the necessary linguistic structures, and their syntactic difficulties are claimed to be consequences of their working memory limitations (Shankweiler & Crain, 1986; Crain et al., 1990; Bar-Shalom et al., 1993).

According to the processing limitation hypothesis, working memory plays an indispensable role in processing both spoken and written language. The data concerning normal and language-disordered children are consistent with the view that (1) phonological memory skills could play a causal role in vocabulary development, (2) phonological memory may be important for the acquisition of letter-sound correspondence rules, (3) a central deficit of language-disordered children affects their abilities to represent material in phonological form in working memory, and (4) working memory is crucially involved in sentence processing (Gathercole & Baddeley, 1989; Crain et al., 1990; Gathercole & Baddeley, 1990). At the word level, the experimental paradigm often used for working memory assessment is nonword or unfamiliar word repetition, since this kind of item, because of its nonlexical status, critically depends on short-term phonological representations. At the sentence level, the paradigm most often used is the act-out procedure, which involves sentences of different syntactic complexity, imposes various demands on working memory resources, and does not require verbal output.

In this paper, we compare the language and verbal memory skills of 26 French dyslexic children to those of 26 normally developing children matched in age and 26 younger children. The tasks, derived from the *L2MA Battery* (Chevrie-Muller et al., 1997), involve (1) memory skills (digit span, unfamiliar word repetition, sentence repetition); (2) word retrieval (with semantic, phonological and grammatical criteria); (3) sentence processing (with verbal and act-out production). The paper focuses on the relationships between language processing (at the word and sentence level), working memory, and verbal/nonverbal output. The first question we addressed was whether dyslexic children experience comparable difficulties when the tasks involve word retrieval with phonological, semantic, or grammatical demands. The second question was whether sentence processing is different when the required output is verbal versus nonverbal. The third hypothesis explored the role of working memory in word repetition, word retrieval, and sentence processing with or without verbal output. The last question was to determine the nature of language/memory difficulties in dyslexic children: do they represent a simple developmental lag or a specific impairment? The lag hypothesis suggests that dyslexic children operate at a less mature linguistic level than their age-mates and should display a similar language profile to younger children; thus, the oral language disorders appear to be closely related to the reading failure. The specific impairment hypothesis suggests that the dyslexics' language profile is atypical when compared to that of both age-mates and younger children; the oral language disorders are assumed to antedate the reading disability.

METHOD

Subjects

Twenty-six children were selected because they met the criteria for specific reading impairment. They were all diagnosed as dyslexics and did not exhibit overt speech-language disorders. The mean age of these children was 125 months. The mean global IQ of the group was 96.1 (range: 84–114), verbal IQ was 93 (range: 82–113), and performance IQ was 99.3 (range: 77–124). The control groups comprised 52 children: 26 normally developing children matched in age (mean age: 121 months; 17 of them attended Grade 5 and 9 attended Grade 4) and 26 normally developing younger children (mean age: 105 months) attending Grade 3.

The diagnosis of dyslexia was confirmed in our study by reading and spelling assessments, as follows:

(1) The *reading assessment* involves four scores:

R1: Pseudoword deciphering. This task requires the mastering of grapheme–phoneme correspondence rules and the assembly strategy (20 items).

R2: Irregular word reading. This task requires the addressed strategy and orthographic knowledge (10 items).

R3: Regular word reading (10 items). This task requires both addressed and assembly strategies.

TABLE 1

Reading Skills in the Dyslexic Children (DL), the Age-Matched Group (A-CTR), and the Younger Children (B-CTR): Mean Scores and Standard Deviations

	R1	R2	R3	R4
DL	9.4–3.8	4.9–2.8	9–1.5	6.7–2.5
A-CTR	19.5–1.1[a]	9.7–.5[a]	10–0[b]	9.2–.9[a]
B-CTR	19.5–.7[a]	9.3–1.2[a]	10–0[c]	8.9–.9[a]

[a] $p < .0005$.
[b] $p < .005$.
[c] $p < .001$.

R4: Incomplete sentence reading and selection of the missing word in a set of 5 words (10 items). This task requires sentence processing and comprehension.

Tasks R1, R2, and R3 were based on the dual route model of reading. According to that model, two forms of phonological mediation can be used during written word identification. Addressed phonological mediation occurs when a phonological item (a real word) is activated directly from the orthographic lexicon and converted into a phonological code. Assembled phonology depends not on stored lexical phonology, but on the application of letter-sound correspondences. Assembled phonology is necessary for reading pseudowords or unknown words.

(2) The *spelling assessment* involves two scores:

S1: Nonsignificant syllable spelling (10 items). This task requires the mastering of phoneme–grapheme correspondence rules and the assembly strategy.

S2: Dictation (calculated out of 50 points). This task requires phonetic, orthographic, and grammatical skills.

For each reading and spelling task, the scores of the dyslexic children were compared to those of the age-matched group and the younger children see Tables 1 and 2).

Comparisons of the reading and spelling scores reveal significant differences between the dyslexic children and the two control groups. The dyslexic children performed poorly on all tasks, and particularly on those which involved pseudowords and irregular words. These results establish that the dyslexic children had not mastered the grapheme/phoneme/grapheme correspondence rules and exhibited deficiencies in addressed lexical processing (orthographic buffer).

TABLE 2

Spelling Skills in the Dyslexic Children (DL), the Age-Matched Group (A-CTR), and the Younger Children (B-CTR): Mean Scores and Standard Deviations

	S1	S2
DL	5.5–2.6	17.7–9.6
A-CTR	10–1[a]	40.8–6.7[b]
B-CTR	8.9–.9[b]	36.2–5.5[b]

[a] $p < .005$.
[b] $p < .0005$.

Experimental Procedure

The experimental procedure involved (1) immediate verbal memory, (2) word retrieval and verbal production, (3) sentence processing and verbal production, (4) sentence processing and act-out production.

Immediate verbal memory. (1) The word repetition task required the child to repeat 10 unfamiliar words which contained consonant clusters (such as *pseudonyme* or *perspicace*) or similar phonemes (such as *sèche-linge* or *chasse-neige*).

(2) The digit-span task required the child to repeat series of digits forward and backward.

(3) The sentence repetition task required the child to repeat four sentences.

Word retrieval and verbal production. (1) The verbal fluency task required the child to generate the most possible words in one minute (a) with a phonological criterion (generating words starting with the sounds P and F), and (b) with a semantic criterion (generating words about jobs, sports and holidays).

(2) The complementary/contrary task required the child to retrieve the antonyms of five nouns, three adjectives and two verbs. For example: ''Inside and . . . ?'' (the correct response is ''outside'') or ''to forget and . . . ?'' (the correct response is ''to remember'').

Sentence processing and verbal production. (1) The verb processing task required the child to use a correctly tensed verb in five sentences. For example: ''Pierre learns. Pierre and Jean . . . ?'' (the correct response is ''learn'').

(2) The syntactic completion task required the child to complete five auditorily presented sentences. For example: ''Mary passed her exam; nevertheless, she is not happy. Mary is not happy . . . ?'' (the correct response is ''although she passed her exam'').

Sentence processing and act-out production. The act-out task required the child to listen to 14 sentences and then act them out using geometric shapes. The operations required in the task involved substitution (two items), temporality (four items), alternative (one item), topology (three items), conditionality (two items) and restriction (two items). The sentences were, for example, ''If there is a yellow star, remove a red star'' or ''Arrange the shapes two by two, except the red ones.''

RESULTS

Two types of statistical analyses were performed: a multiple regression analysis and an analysis of variance (ANOVA).

The purpose of the multiple regression analysis was to examine the relationship between individual differences in auditory-verbal memory and linguistic skills such as word retrieval and sentence processing; another purpose was to determine whether memory contributed similarly to performance on sentence processing with and without verbal output. The analysis of variance was performed to examine whether dyslexics and good readers exhibited significant group differences in their performance on the different tasks.

Multiple Regression

The multiple regression analysis treated the fluency, complementary, syntactic completion, and act-out tasks as the respective dependent variables, and word repetition, sentence repetition and digit repetition as independent variables.

The analysis revealed (1) a significant contribution by word repetition ($F(3, 78) = 11.16$, $p < .0005$), sentence repetition ($F(3, 78) = 15.88$, $p < .005$), and digit repetition ($F(3, 78) = 11.7$, $p < .005$) in the syntactic completion task; (2) a significant contribution by word repetition ($F(3, 78) = 13.6$, $p < .0005$), sentence repetition ($F(3, 78) = 6.1$, $p < .05$), and digit repetition ($F(3, 78) = 7.4$, $p < .05$) in the complementary task.

We found that:

(1) approximately 24% of the variance in the subjects' syntactic completion task was accounted for by sentence repetition, 18% by word repetition and 18% by digit repetition;

(2) 35.8% of the variance in the subjects' complementary task was accounted for by digit repetition, 21.5% by word repetition, and 11.4% by sentence repetition;

(3) 15.3% of the variance in the subjects' act-out task was accounted for by sentence repetition.

ANALYSIS OF VARIANCE

Immediate Verbal Memory

(a) Digit recall. Compared to both the age-matched group and the younger children, the dyslexic children's scores were significantly lower for digit recall, forward ($F(1, 52) = 17.5$, $p < .0005$, and $F(1, 52 = 18.6$, $p < .0005$), and for digit recall, backward ($F(1, 52) = 5.8$, $p < .05$, and $F(1, 52 = 15.9$, $p < .0005$).

(b) Word repetition. Compared to the age-matched group and the younger children, the dyslexic children showed poorer performance on word repetition (F (1, 52) $= 51.9$, $p < .0005$, and $F(1, 52) = 54.5$, $p < .0005$).

(c) Sentence repetition. Compared to both the age-matched group and the younger children, the dyslexic children performed worse on sentence repetition ($F(1, 52) = 24.5$, $p < .0005$, and $F(1, 52) = 6.1$, $p < .05$).

Word Retrieval and Verbal Production

(a) Verbal fluency: phonological criterion. Compared to the age-matched group and the younger children, the dyslexic children's scores were significantly lower on the phonological fluency task ($F(1, 52) = 25.3$, $p < .0005$, and $F(1, 52) = 4.4$, $p < .05$).

(b) Verbal fluency: semantic criterion. Compared to the age-matched group, the dyslexics' scores were significantly lower on the semantic fluency task ($F(1, 52) = 17.7$, $p < .0005$). In contrast, their performance was similar to that of the younger children.

(c) Complementary task. Compared to the age-matched group, the dyslexic children performed worse on noun retrieval ($F(1, 51) = 6.5$, $p < .05$), adjective retrieval ($F(1, 52) = 13.7$, $p < .001$) and verb retrieval ($F(1, 52) = 17.5$, $p < .0005$). Compared to the younger children, they performed significantly worse on adjective retrieval ($F(1, 52) = 6.8$, $p < .05$) and verb retrieval ($F(1, 52) = 4.8$, $p < .05$) but similarly on noun retrieval.

Sentence Processing and Verbal Production

(a) Verb processing task. Compared to the age-matched group, the dyslexic children showed a lower level of performance on verb processing ($F(1, 52) = 14.8$, $p < .0005$). However, their performance was similar to that of the younger children.

(b) Syntactic completion task. Compared to the age-matched group and the younger children, the dyslexic children's performance on the syntactic completion task was poorer ($F(1, 52) = 10.2$, $p < .005$, and $F(1, 52) = 6.4$, $p < .05$).

Sentence Processing and Act-Out Production

Compared to the age-matched group, the dyslexic children showed poorer performance on the sentences involving substitution ($F(1, 52) = 7$, $p < .05$), temporality ($F(1,52) = 16$, $p < .0005$), topology ($F(1, 52) = 17.7$, $p < .0005$), and conditionality ($F(1, 52) = 5.6$, $p < .05$), and performed at a similar level for the sentences involving alternative and restriction. In contrast, their performance was similar to that of the younger children for the whole task.

DISCUSSION

Compared with their age-mates, the dyslexic children exhibited a significant deficit affecting all tasks (except for the alternative and restriction items in the act-out task). These results confirm that the reading impairment goes together with oral language disorders related to word retrieval, verbal short-term memory, syntactic processing, and semantic production. They are consistent with the hypothesis that certain language deficits in dyslexia are closely related to the reading disorder of which they could appear to be secondary consequences.

Compared with the younger children, the dyslexic children exhibited a significant deficit on all the memory tasks, the phonological fluency task, the adjective and verb retrieval portions of the complementary task, and the syntactic completion task. In contrast, the dyslexic children and the younger children performed similarly on the semantic fluency task, the noun retrieval task, the verb processing task, and the entire act-out task. These results suggest that the observed oral language disorders involve heterogeneous components.

The most difficult task for the dyslexic children was word repetition. This task, which requires immediate verbal memory, involves low-frequency words with consonant clusters or similar phonemes. Although the dyslexic children did not display any articulatory deficits, they were significantly impaired at this task. They had a selective difficulty in retrieving the phonological codes of these words, encoding their full segmental phonological representations, and planning the articulatory movements that correspond to the stored phonological sequences. The second most difficult memory task was digit repetition, which also requires immediate verbal memory and the storage function of working memory. Nevertheless, this traditional measure of phonological memory does not make the same demands on the child's articulatory skills as word repetition. This probably explains why word repetition was more impaired than digit repetition. The third most difficult memory task was sentence repetition, which requires immediate verbal memory, ability to maintain items and order information, and articulatory planning. The fact that the semantic coding is important in sentence processing probably explains why the children were somewhat less impaired at this task than at word repetition. Unlike the unfamiliar words, the digits and the words used in the sentences are familiar items stored in long-term memory. Previous data had provided support for the hypothesis that long-term memory processes make a significant contribution to memory span performance. In contrast, unfamiliar items lack representations in long-term memory and, in that sense, they may provide a pure measure of the operation of the articulatory loop of working memory (Hulme et al., 1991).

Compared to the younger children, the dyslexic children had significantly lower scores for tasks requiring word retrieval with a phonological constraint (phonological fluency task) or a cognitive constraint (complementary/contrary task, which involves the notion of opposite). In contrast, when word retrieval was semantically based (semantic fluency task), the dyslexics' performance was similar to that of the younger children. The semantic fluency task requires word retrieval with a preselected category (sport, job or holiday). Consequently, the word association required by this task, which may be based on the child's personal experience, relies on long-term memory storage. This is not the case in the phonological fluency and contrary tasks, which place strict conditions on phonetic and cognitive criteria, and thus require a more constrained word association and an indirect long-term memory access.

With regard to sentence processing, the results were also very different. The dyslexic children experienced difficulties with the syntactic completion task, which requires one to listen to/understand/retain sentences, and to partially transform them using prepositions and conjunctions. The difficulties probably relate to the complexity of the task, which implicates working memory and requires word retrieval (of abstract function words), sentence transformation, syntactic planning and articulatory production. In contrast, the dyslexic children performed similarly to the younger children in the verb processing task, which requires only verb transformations, and in the act-out task, which requires one to listen to/understand/retain sentences and to act them out using geometric shapes. Although the act-out task depended on working memory and required syntactic processing and physical planning, the dyslexic children had no difficulties with it. Moreover, they accurately performed the more complex items of the act-out task, such as the temporal and conditional items which involve adverbial clauses (''After you have taken the blue shapes, take the squares too'' or ''If there is the same number of stars and of squares, take one of each''). These clauses introduce conflicts between order of mention and conceptual order and dramatically stress working memory (Crain et al., 1990).

Taken together, the results show that (1) the dyslexic children's memory skills were limited; (2) individual differences in memory for words, digits and sentences partially accounted for performance on the phonological fluency, syntactic completion, and contrary tasks; (3) only individual differences in sentence memory accounted for the act-out task; (4) sentence processing was impaired inasmuch as the tasks required working memory, word retrieval and verbal production. These results are partially consistent with the processing limitation hypothesis, which assumes that the repetition difficulties observed in dyslexic children may reflect a capacity limitation of the phonological component of working memory, and which expect nonword repetition to be even more sensitive to impaired phonological storage than memory span for words or digits (Gathercole and Baddeley, 1990).

Nevertheless, the various discrepancies observed between the tasks suggest complementary hypotheses. The facts that (a) word retrieval was impaired with the phonological and cognitive constraints, and not with the semantic criterion, and (b) the difficulty of sentence processing depended on whether the required output was verbal or nonverbal, suggest that the core difficulty is the formulation of cognitive plans from auditory input to verbal output. Insofar as tasks mediated word retrieval by making cognitive, phonetic or articulatory demands, and therefore constrained long-term memory access, the plan from input to output (word production) appeared to be disordered in dyslexic children. Insofar as tasks associated sentence transformations, retrieval and use of function words, and verbal production, the plan from input to output (sentence production) appeared to be impaired in dyslexic children. Conversely, when the plan did not involve verbal production, sentence processing was efficient, even though the task required working memory involvement, the use of function words and complex interpretations of sentences.

Our final goal was to determine the nature of language/memory difficulties in dyslexic children: do they represent a simple developmental lag or are they a specific impairment? The fact that the dyslexic children operated at a less mature linguistic level than the younger children on several tasks suggests that memory limitations, phonological processing and formulation of plans from auditory input to verbal input are part of an atypical pattern of linguistic development.

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Lexical and Syntactic Errors in Translation by Italian/English Bilinguals

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Translation is recognized as a specific linguistic ability in bilinguals. Yet, we know little about what factors influence translation ability, especially at the sentence level. In this study, adults were asked to translate sentences from English (L2) into Italian (L1). We hypothesized that (1) adults with later age of arrival in Canada would perform better in translating into their native language than adults with earlier age of arrival, and therefore earlier L2 acquisition and (2) adults with higher use of L1 would perform better than adults with low use. Participants ($N = 70$) formed 4 groups based on their age of arrival in Canada (AoA) and their reported use of Italian. The translated sentences were scored for syntactic and lexical correctness, and for the number of omitted words. There were significant AoA group effects: late arrival in Canada was associated with better performance. There were no effects for reported frequency of use of Italian Both self-ratings and native Italian listener ratings of the translated sentences correlated highly with number of correct sentences.

INTRODUCTION

Translation from one language to another is a distinct linguistic skill in bilinguals (Grosjean, 1997; Paradis, Goldblum, & Abidi, 1982). Translation has been used extensively to study lexical processing in bilinguals. However, most studies use tasks involving only single words (for recent review see Kroll & De Groot, 1997). It is not clear whether performance on single word translation tasks correlates with other linguistic abilities because most studies of translation use only single words and do not extensively test other speech or language skills.

A series of studies by Flege and colleagues has examined performance on multiple tasks in a group of Italian/English bilingual adults, allowing us to compare performance across tasks. Flege, MacKay, and Piske (in press) found independent effects for both age of arrival (AoA) in Canada and amount of L1 (Italian) use on two speech measures: degree of foreign accent and duration of English sentences. However, on two language measures, effects of AoA but not L1 use were observed: self-rating of ability to translate sentences from English into Italian and ratings of semantic accuracy of the translations by 6 native listeners.

Two problems with this study were: (1) that the listeners only rated the semantic adequacy of the translations, not their lexical or syntactic adequacy; and (2) that both ratings were subjective: one done by the listeners before attempting the translation and one done by judges who listened to the English sentences, then the Italian translations. In both cases the ratings could have been influenced by the levels of bilingualism of the raters, or by other confounding factors.

The present study examines the sentence translation task using an objective scoring of the translated sentences and explores the relationship between these scores and other language abilities and self-ratings of bilingualism. The following 3 hypotheses were tested:

1. the early AoA groups will have lower scores on the translation task than the late arrivals;
2. the high use groups will have higher scores on the translation task than the low use groups;
3. since the translation self-ratings correlate with the listener ratings, we hypothesize that both will correlate with objective scores on the translation task.

METHOD

Subjects

Seventy-two native Italian speakers participated (see Flege, MacKay, & Piske, in press, for detailed descriptions of the subjects and the stimuli). They formed 4 groups ($N = 18$ each) based on use of Italian (Low: 1–15% or High: 25–85%) &and age of arrival in Canada (Early: mean 7 years or Late: mean 20 years). Age of arrival and use of Italian were determined to be independent factors. The Low and High Use groups did not differ significantly in the number of years of education in Canada, or in length of residence ($p > .10$). For the present study, two subjects in the Early Arrival/Low Use group were eliminated: one because she did not attempt any of the sentences and one because he had a strong dialect.

Task

Subjects translated 30 sentences from English into Italian. Sentences were chosen to represent 3 levels of difficulty within each of 10 domains (e.g., sports, home, religion). From 25 of these sentences, 74 words with few possible correct translations (determined by 2 native speakers of Italian) were retained for the present study. There were 48 nouns, 21 verbs, and 5 adjectives.

Analysis

The dependent variables were:

1. the number of sentences in which all selected words were correct

2. number of lexical errors (all types combined): semantically related, circumlocutions, empty or very general words (e.g., someone/referee), false cognates (e.g., *silko* rather than *seta* for silk), and English words. Number of syntactic errors (all types combined): agreement for gender or number, changing the verb tense from the English stimulus sentence, and changing a noun from singular to plural or vice versa.

3. Omitted words: no attempt or ‘‘I don’t know’’ type responses.

4. Other errors, including phonologically similar words or nonwords (e.g., *carna/carne*).

The group means for each dependent variable were submitted to an Analysis of Variance, using Tukey’s Honestly Significant Difference for post-hoc testing of group differences. Correlations between the variables listed above on the one hand, and self-ratings, foreign accent, and speaking time (as described in Flege, MacKay, & Piske, in press) were also calculated.

RESULTS

The scores for the 4 groups are shown in Table 1.

Few subjects were able to correctly translate the sentences. Of the 25 sentences, the maximum score achieved was 12/25, and the group means are all below 6/25 correct. Omitting words was the most frequent error type, followed by lexical selection errors. Although one might have expected the Early Arrival groups to use more English words and to insert more false cognates to fill in gaps in their Italian vocabulary, this did not occur. For all groups, the mean number of cognates + English words was approximately 2.

Within this pattern of poor performance, there were significant between-group differences for two variables. For both Low Use groups, AoA significantly affected the

TABLE 1
Lexical and Syntactic Performance by Group

		Early low	Early high	Late low	Late high
Correct sentences	Mean	3.40	4.5	6.1**	5.4
	SD	2.13	2.6	2.1	2.7
	Range	1–8	1–11	3–11	2–12
Omitted words	Mean	24.06	21.72	10.17** +	12.39** +
	SD	12.64	11.80	6.74	10.39
	Range	6–50	7–40	1–27	1–39
Lexical errors ($p = .062$)	Mean	11.19	12.33	13.56	14.78
	SD	4.74	3.48	4.82	3.21
	Range	6–22	6–18	6–22	8–20
Syntactic errors	Mean	3.00	3.23	3.56	4.06
	SD	1.63	2.27	2.15	2.18
	Range	1–6	1–9	1–10	0–8
Other errors	Mean	1.44	1.44	1.00	1.50
	SD	1.26	1.10	1.50	1.30
	Range	0–4	0–3	0–6	0–4
Cognates and English	Mean	1.81	1.89	2.17	2.00
	SD	1.68	1.78	1.58	2.19
	Range	0–6	0–6	0–6	0–8

Note. Asterisks indicate significant differences between the Early-low group and the one marked using Tukey's Honestly Significant Difference: $*p < .05$, $**p \leq .01$, $***p \leq .002$; (+) indicates significant difference between the Early High group and the one marked: $+p < .05$, $++p < .01$. Because cognates have been studied in the bilingualism literature, they are listed in this table separately, but they are also included in the broader Lexical Errors category.

number of correct sentences and the number of omitted words (these two dependent variables were highly correlated with each other: −.605, $p < .001$). The Early–Low group differed from the two Late Arrival groups in the number of omitted words, as did the Early–High group (see Table 2).

The correlations highlight the importance of omitted words, with strong, negative correlations between Omitted Words and both Correct Sentences and Lexical Errors. Correct Sentences and Omitted Words both strongly correlated with the self-ratings

TABLE 2
Correlations between Dependent Variables ($N = 70$)

	Syntactic errors	Correct sentences	Omitted words	Lexical errors
Correct sentences	—	−.605***	−.167	−.256
Omitted words			−.439***	−.094
Lexical errors				.153
Syntactic errors				
Other errors	−.099	−.172	.266	.193
Foreign accent in English[a]	−.243 ($p = .043$)	−.373	−.193	−.216
Duration of Italian sentences[a]	−.361**	.299*	.070	.114
ISP self-rate speak Italian[a]	.481***	−.475***	.150	.146
ESP self-rate speak English[a]	−.151	.261	−.206	−.095
Self-rating translate hardx[a]	.399***	−.804***	.506***	.128
Listener ratings of translation[a]	.680***	−.868***	.227	−.031

Note. $***p < .001$; $**p \leq .01$; $*p < .02$, two tailed tests.
[a] Data from Flege, MacKay, & Piske, in press.

of translation ability and the listeners' semantic judgements but did not correlate with foreign accent.

DISCUSSION

AoA had a significant effect on performance, with early arrivals performing below late arrivals, confirming Hypothesis 1, and extending previous findings that AoA affects both speech and language abilities. Contrary to Hypothesis 2, language use did not affect scores. This finding confirms the result obtained using subjective ratings in Flege, MacKay, and Piske (in press). However, note that the ''higher use'' group began at only 25% L1 use. It may be that the large range of L1 use in this group masked a ''use'' effect.

The objective scoring correlated highly with listener ratings and also with self-ratings done before the task. Lexical errors and omitted words correlate with self-ratings suggesting that vocabulary may be a key factor on which participants base their self-rating of speaking ability.

The poor performance on the translation task by all groups could indicate significant attrition of Italian or its imperfect acquisition or limited English skills. The low scores may also reflect the fact that normal bilinguals do not translate sentences. They use each language where appropriate, but translation is a specific skill, separate from knowledge of each language (Grosjean, 1997). Further work is needed to isolate the impact of each of these factors.

The literature on L1 attrition has identified native language use and age of second language acquisition as two factors, among many, which can influence changing L1 abilities, but there are conflicting results as to their importance (e.g. Bahrick et al., 1994; Kohnert, Hernandez, & Bates, 1998; Weltens & Grendel, 1993). The present study, especially when considered with the other studies of these same adults, highlights the fact that different types of linguistic abilities may be differently affected by L1 use and age of acquisition.

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The Impact of Age at Seizure Onset on the Likelihood of Atypical Language Representation in Children with Intractable Epilepsy

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Studies have suggested that early postnatal lesions are associated with a greater likelihood of atypical speech representation than lesions acquired later in life. Comparison groups have been defined differently across studies, with age typically being treated as a dichotomous (i.e., early versus late lesion onset) rather than continuous variable. Thus, little is known about the age at which children become less likely to exhibit atypical representation following a brain insult. This study examined the likelihood of typical versus atypical speech representation in children with intractable epilepsy ($n = 75$). Age of seizure onset was treated as a *continuous* variable to examine whether there was a naturally occurring cut-off point after which the rate of atypical speech representation decreased. A much higher proportion of children with seizure onset *prior* to the fifth year showed atypical speech representation as compared to children whose seizures began after 5 years of age.

INTRODUCTION

Several studies involving pediatric or mixed (adult and child) samples have suggested that the development of atypical language representation (i.e., bilateral or right hemisphere language dominance) is more likely when there is an early (compared to late) lesion. The definition of ‘‘early’’ and ‘‘late’’ onset varies across studies. Muller, Rothermel, Behen, Muzik, Chakraborty, and Chugani (1999) found that patients with unilateral left lesions before 5 years of age were more likely to have right hemisphere activation on PET during language tasks than individuals with lesions after the age of 20. Duchowny, Jayakar, Harvey, Resnick, Alvarez, Dean, and Levin (1996) reported findings from language mapping via subdural grids in six children with postnatal left hemisphere insult. Those with atypical speech representation ($n = 3$) all had onset prior to the fifth year, while those with onset between 6 and 16 years of age all had preserved left hemisphere language representation. Rey, Dellatolas, Bancaud, and Talairach (1988) found that the age of seizure onset in individuals with intractable epilepsy was significantly earlier for those with right (versus left) hemisphere language representation.

Each of these studies provides support for the increased likelihood of finding atypical language representation following an early postnatal lesion as compared to a lesion of later onset. While this may be true, little is known about the pattern of atypical language representation when age of onset is treated as a continuous variable. In other words, rather than creating an *a priori* division between ‘‘early’’ and ‘‘late’’ onset groups, one could ask if there is a naturally occurring cut-off point after which the rate of atypical speech representation in children decreases compared to children with onset prior to that age. This was the goal of the present study. The relatively large overall sample of children who underwent the pre-operative Intracarotid Amobarbital procedure (IAP), including a subset of children with atypical language representation ($n = 21$), afforded the opportunity to (1) examine language dominance continuously as a function of the age at seizure onset, and (2) investigate the patterns of language dominance in ‘‘early’’ versus ‘‘late’’ seizure onset groups defined in terms of a natural cut-off point. We predicted that, on average, children with atypical language representation would have an earlier age of seizure onset than those with later onset. Similarly, we expected that the incidence of atypical speech representation would be higher at the younger ages of onset.

SUBJECTS

Data for 75 patients with intractable seizures who underwent IAP as part of their pre-surgical work-up at the Hospital for Sick Children between 1982 and 2000 were retrieved retrospectively from the medical charts. The sample consisted of 37 males and 38 females ranging in age from 6.25 to 18.08 years at the time they were seen in the Psychology Department.

PROCEDURE

Speech lateralization was determined by IAP. Sodium amobarbital was injected, following catheterization of the internal carotid artery. The dose of sodium amobarbital was titrated to body weight. In accordance with standard practice for the IAP at the Hospital for Sick Children, the dose of sodium amobarbital administered was 1.5 mg/kg injected into each hemisphere. Both hemispheres were tested on the same day with a brief interval between the two tests. The speech protocol used was individualized to the child, taking into consideration the child's age, developmental level, and speech ability. Baseline testing was carried out prior to injection in order to compare performance to that when the drug was circulating. Whenever possible, the child was asked to count at the time of the injection, and this was followed by tests of naming pictures and/or objects. Spelling, reading, and/or reciting the days of the week or the alphabet, were also assessed when the child was capable of such tasks. EEG monitoring for the presence of slow waves, as well as paralysis on the side contralateral to the injected hemisphere were taken as indicators that the injection was successful.

Following the injection, indications of speech representation within the hemisphere were speech arrest and/or errors on tasks the child was capable of performing perfectly at baseline. If the injection was deemed successful, a patient was classified as having bilateral speech representation if s/he demonstrated at least one of the following: (a) no speech arrest or errors when either of the hemispheres was injected (i.e., duplication of speech representation), (b) a similar number of errors and of comparable levels following injection of either hemisphere (i.e., speech representation shared between the hemispheres), or (c) a qualitatively different pattern of speech errors following injection of either hemisphere (i.e., speech specialization distributed between the hemispheres).

For the purposes of this study, children with IAP results indicative of left hemisphere speech representation were classified as having ''typical'' speech representation ($n = 54$), while those with right hemisphere ($n = 2$) or bilateral results ($n = 19$) were designated as having ''atypical'' speech representation. Individuals with inconclusive IAP results were excluded from the sample.

RESULTS

As predicted, children with atypical language representation were, on average, younger at the time they began having seizures ($F(1, 75) = 5.681$, $p < .05$). The mean age at seizure onset for children with atypical language representation was 4.35 years ($SD = 3.85$), as compared to 6.95 years ($SD = 4.26$) for children with typical (i.e., left hemisphere) language representation.

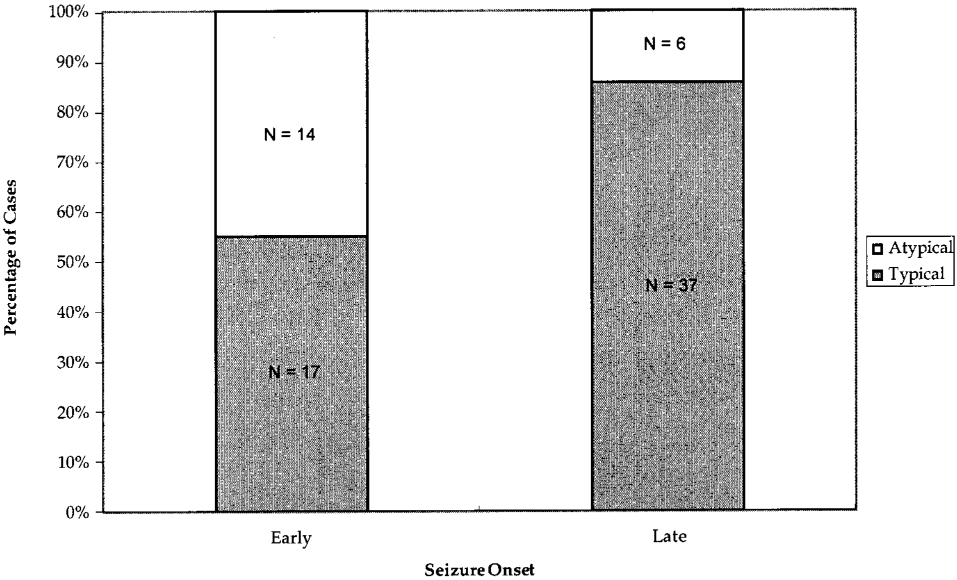

FIG. 1. The occurrence of typical and atypical language representation in children with early (<5 years) vs late seizure onset (≥ 5 years).

In considering the number of children with typical and atypical language representation at each age of onset (i.e., at 1 year of age, at 2 years), it became apparent that a much greater proportion of children whose seizures began prior to their fifth year had atypical language dominance compared to children with seizure onset between 5 and 16 years of age. At each age of onset below five years of age, anywhere from 2 to 5 children had atypical speech representation as determined by the IAP. In contrast, only single cases of atypical representation were noted in the 6-, 8-, 9-, and 12-year-old groups. Two children with seizure onset at 11 years of age also had atypical speech representation. Thus, the five-year age marker emerged as a reasonable cut-off point, above which the likelihood of developing atypical speech representation appeared to markedly decline. When the data were subsequently reorganized to reflect the ''early'' and ''late'' seizure onset groups (i.e., those with onset before or after 5 years old), the result was highly significant ($\chi^2 = 8.548$, $p < .005$). Children with seizure onset before 5 years of age were significantly more likely to have atypical language representation than those children with seizure onset between 5 and 16 years of age. This result is shown in Fig. 1.

It was difficult to assess whether children with left versus right seizure foci exhibited the same pattern of language dominance according to their age at seizure onset since only 2 children with right-sided seizures had atypical speech representation. Nonetheless, in both groups (left- and right-hemisphere seizures) children with atypical speech representation tended to have earlier seizure onset and the interaction between language dominance and seizure side was not significant ($F(1, 69) = .81$, $p = .37$).

DISCUSSION

The results of previous studies have suggested that individuals who sustain a brain insult early in childhood are more likely to develop atypical speech representation than those who develop similar lesions at a later age. The question of what constitutes ''early'' versus ''late'' onset has been difficult to address, in part due to small sample sizes to date. It was of particular interest in this study to examine whether we could observe a pattern in the rates of atypical and typical speech representation in children with seizure onset ranging from birth to 16 years of age.

Consistent with the results of previous studies, children with atypical language representation were found to have an earlier onset of seizures. Perhaps more interesting was the fact that almost 50% of children whose seizure onset predated their fifth birthday had atypical speech representation. This came in stark contrast to the mere 14% of atypical speech representation in children whose seizures developed beyond the age of 5. Thus, the fifth year appears to represent a reasonable demarcation point beyond which the rate of atypical speech representation in children with intractable seizure disorder is considerably reduced. Moreover, this relationship appeared to hold true both for children with left- and right-sided seizure foci. These results lend support to previous findings in which the age of 5 years was used as an *a priori* cut-off point in determining early versus late onset, and confirms that the age at which a child sustains a brain insult likely plays a significant role in outcome of atypical speech representation.

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Linguistic and Nonlinguistic Auditory Processing of Rapid Vowel Formant (F2) Modulations in University Students with and without Developmental Dyslexia

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To help resolve the issue of whether developmental dyslexia (DD) is related to central auditory processing deficits or to language-specific processing deficits, we had nine dyslectic and nine nondyslectic right-handed undergraduate students perform linguistic (Experiment 1: phoneme identification) and nonlinguistic (Experiment 2: formant rate change detection) tasks. In Experiment 1, subjects listened to synthetic vowels whose second formant (F2) was modulated sinusoidally with F1, F3, and F4 held constant. F2 modulation rate (4–18 Hz) was manipulated within and across stimuli. The groups did not differ in phoneme identification. Experiment 2 was run three times and showed that the control subjects' performance improved across runs whereas the dyslexics' deteriorated across runs ($p < .0001$), suggesting practice and fatigue effects, respectively. Performance on the two experiments correlated significantly and negatively for the dyslexic subjects only. These results suggest that resource depletion or frontal lobe dysfunction may be implicated in developmental dyslexia.

INTRODUCTION

An ongoing debate is whether developmental dyslexia (DD) is related to a central auditory processing deficit (CAPD) or to a language-specific processing deficit (LSPD). Those in favor of the LSPD hypothesis (e.g., Mody et al., 1997) provide evidence that individuals with DD perform as well as normal readers on nonlinguistic tasks, but more poorly on linguistic tasks. Those in favor of the CAPD hypothesis (e.g., Hari & Kiesila, l996; McAnnaly & Stein, 1997; Tallal, 1980) provide evidence that individuals with DD perform more poorly than normal readers on tasks that involve processing of both speech and non-speech stimuli, provided that the tasks involve fine and precise processing and integration of rapidly changing acoustic signals.

Tallal (1980), a strong advocate of the CAPD hypothesis, has argued that children with DD have poor ability to perceive signals that follow one another rapidly and exceptional difficulties in perceiving signals that are very brief or that change rapidly over a brief time. According to her, such general auditory deficits impact negatively on the child's ability to process rapidly changing formants and other brief speech events, which in turn affects his or her speech perception and the normal acquisition of language and reading skills. Since the second formant (F2) plays a major role in the perception of phonemes, Tallal (1980) especially implicated abnormal processing of F2 transitions as the major, though not the sole cause, of DD.

To a large extent, the difficulty in resolving the CAPD-LSPD issue has to do with methodology (Mody et al., 1997). Thus far, researchers have used speech and non-speech stimuli to differentiate between LSPD and CAPD, respectively. However, these stimuli have very different acoustic characteristics and are likely to be processed differently in the brain, depending in part on the linguistic or nonlinguistic nature of the task (see Gandour et al., 1998; Ivry & Lebby, 1998). The present study attempts to avoid this problem by having subjects process the same speech-like (synthesized) acoustic stimuli in a linguistic and a nonlinguistic manner.

METHOD

Participants

Nine Hebrew-speaking undergraduate students with DD and nine without participated in the study. They were all right-handed, healthy, with normal speech, language, and hearing. All participated in the study voluntarily, received financial reward for their participation, and were naive to the purpose of the study. All of the dyslexic participants have a history of reading and writing disability. All had been tested on the WAIS-R or the WISC-R during childhood or adolescence and had revealed substantial differences between subscales. They all had subsequently been referred to the Israeli Society for the Advancement of Learning Disabled Children ('Nitzan'), where they had been given a variety of didactic assessment tests and had received a diagnosis of developmental dyslexia. On the basis of this diagnosis they were all receiving special help in the university.

Stimuli

The stimuli used in this study, each 2-s long, were computer-synthesized with the Avaaz Innovation CSRE 4.5 software, based on Klatt's (1980) synthesizer. They consisted of four vowel formants, with the first (F1), third (F3), and fourth (F4) formants having a constant center frequency of 500, 3500, and 4200 Hz, respectively.

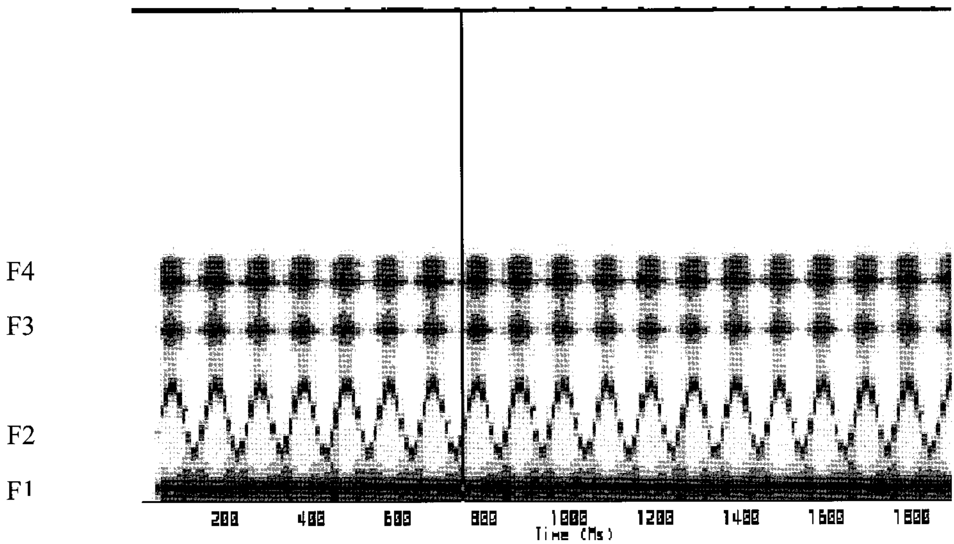

FIG. 1. Synthesized stimulus (S1) with F1, F3, and F4 held constant and F2 modulated sinusoidally at the same rate (10 modulations per second) throughout the duration of the stimulus: *y* axis, frequency (Hz); *x* axis, time (ms).

The center frequency of the second formant (F2) was modulated in a sinusoidal fashion between 1000 and 2400 Hz, to simulate a continuous, repetitive series of the vowels /i/ and /u/, or the diphthong /iu/. The fundamental frequency of all stimuli was held constant at 100 Hz. The intensity of the stimuli was also kept constant throughout the duration of the stimulus and across stimuli. Sound spectrograms of two exemplars of the stimuli are shown in Figs. 1 and 2. When the F2 center frequency was modulated at a slow rate (e.g., 4 ''sinusoidal'' modulations per second), the identity of the vowels was perceptible, whereas at a much higher rate of modulation (e.g., 16 modulations per second) the identity of the vowels was perceptually obliterated.

Three types of stimuli were used. In one type (S1), shown in Fig. 1, the F2 center frequency was modulated sinusoidally at the *same* rate throughout the 2-s duration. In another type (S2), shown in Fig. 2, the F2 center frequency was modulated during the first half of the stimulus at one rate, and during the second half at a *higher* rate. In a third type (S3), the F2 center frequency was modulated during the first half of the stimulus at one rate, and during the second half at a *lower* rate. For both S2 and S3 types, the difference in rate of modulation between the first and second half of the stimulus was by one or two modulations per second (e.g., 4–5, 4–6, 5–4, 6–4).

The three types of stimuli (each presented many times and in random order, see below) were presented to each subject in a sound treated room at a comfortable loudness level via two speakers (Alesis, Model Monitor One) situated in front of and at equidistance (1.5 M, 45°) from the subject. The stimuli were delivered to the speakers from the computer via a reference audio amplifier (Alesis, Model RA-100).

Procedure

Two experiments were carried out, a few minutes apart. In the first experiment participants were presented with type S1 stimuli. Their task was to tell the experimenter what they heard upon hearing the stimulus. S1 was first presented at the highest F2 modulation rate of 18 Hz. Thereafter, on each trial, the rate of F2 modula-

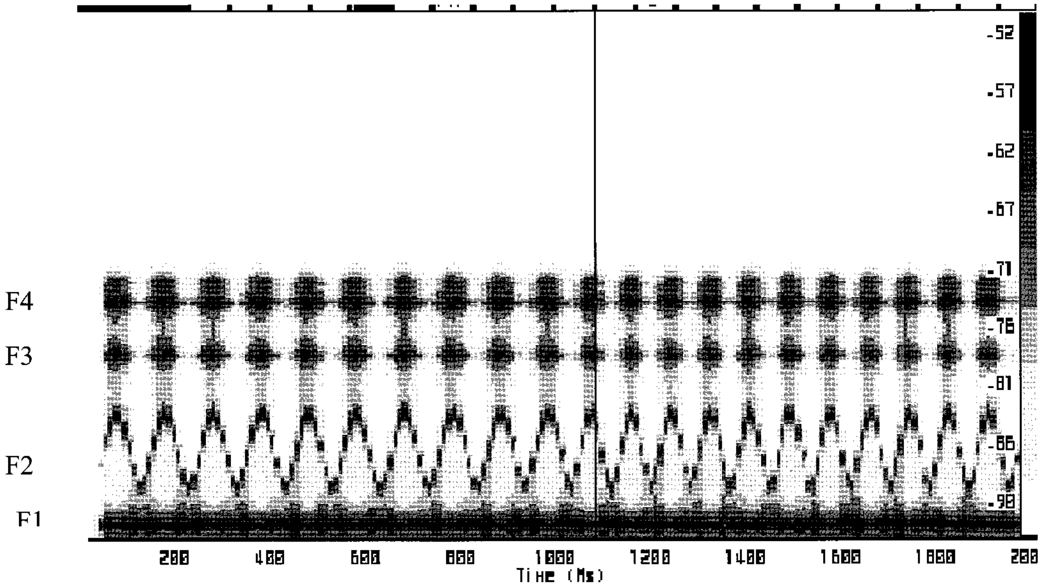

FIG. 2. Synthesized stimulus (S2) with F1, F3, and F4 held constant and F2 modulated sinusoidally at one rate (10 modulations per second) during the first portion of the stimulus and at a higher rate (12 modulations per second) during the second portion of the stimulus:. *y* axis, frequency (Hz); *x* axis, time (ms).

tion was systematically decreased by 1 Hz. This process continued until the participant identified the vowels /i/ and /u/ or the diphthong /iu/. The rate at which the both vowels were identified was the dependent variable. We hypothesized that if DD is related to deficits in phonemic coding of rapidly changing auditory stimuli, then this rate would be lower for the dyslexics than for the controls, since the vowels are more easily identified at lower rates.

In the second experiment participants were presented with the three types of stimuli (S1, S2, S3). Their task was to determine whether there was a change in the *rate* in which the sound they were hearing (i.e., the train of vowels (/i/ and /u/) was modulated, and if there was, to indicate if the second portion of the stimulus was faster or slower than the first portion. Here the stimuli were presented from the slowest modulation rate (4 Hz) to the highest. In this task, the higher the rate of modulation the more difficult it is to detect a change and direction of change. A titration method was used to establish the highest rate at which the participant was correctly able to detect a change and direction of change in F2 modulation beyond chance. This rate constituted the dependent variable. In order to study practice and fatigue effects, we had the participants repeat the second experiment two more times, using the exact procedures as in the first run. The three runs were executed consecutively, with only a few minutes between them. Thus in this task we had two factors: group (dyslexic vs control) and run (first, second, and third).

RESULTS

Experiment 1

There was no difference in phoneme identification threshold between the groups: dyslexics = 10.23, $SD = 1.6$; controls = 9.86, $SD = 2.2$; $t(16) = 0.283$, $p > .05$. Thus, the two groups did not differ in this linguistic processing task.

Experiment 2

The detection thresholds were analyzed with a 2-way ANOVA with Group (dyslexic vs controls) as a between groups variable and Run (first, second, third) as a within-groups variable. The analysis revealed that neither variable had a main effect: Group: $p > .15$; Run: $p > .8$. The interaction between the variables was significant, $F(2, 32) = 17.16$, $p < .0001$. This interaction is illustrated in Fig. 3. Planned comparisons revealed that in the first run, the threshold of the dyslexics was significantly higher than that of the control participants, $F(1, 16) = 4.82$, $p < .05$. In the second run, their threshold was marginally lower than that of the controls, $p < .1$, while in the third run, their threshold was significantly lower than the controls, $F(1, 16) = 12.80$, $p < .005$. In order to explore the effects of practice or fatigue within each group, we compared performance on the three runs separately within each group. The control participants improved their performance significantly between the first and the second run, $F(1, 16) = 7.52$, $p < .05$, and marginally between the second and the third run, $F(1, 16) = 4.01$, $p = .0623$. The difference between the first and the third run was highly significant, $F(1, 16) = 22.52$, $p < .0005$. The performance of the dyslexics deteriorated marginally between the first and the second run, $F(1, 16) = 4.11$, $p = .059$, and nonsignificantly between the second and the third run, $p > .1$. The difference between the first and third run was also highly significant, $F(1, 16) = 12.74$, $p < .005$.

We correlated the performance on the phoneme identification task (Experiment 1) with the performance on the F2 rate change detection task (Experiment 2) for each of the three runs. The correlations in the dyslexics were significant and negative for each of the runs (first: $r = -0.67$, $p < .05$; second: $r = -0.85$, $p < .005$; third: $r = -0.70$, $p < .05$). Thus, the better the dyslexics performed on the first task, the worse they performed on the second task. No significant correlations were observed in the controls (first: $r = -0.31$, $p > .423$; second: $r = -0.07$, $p > .850$; third: $r = -0.24$, $p > .52$).

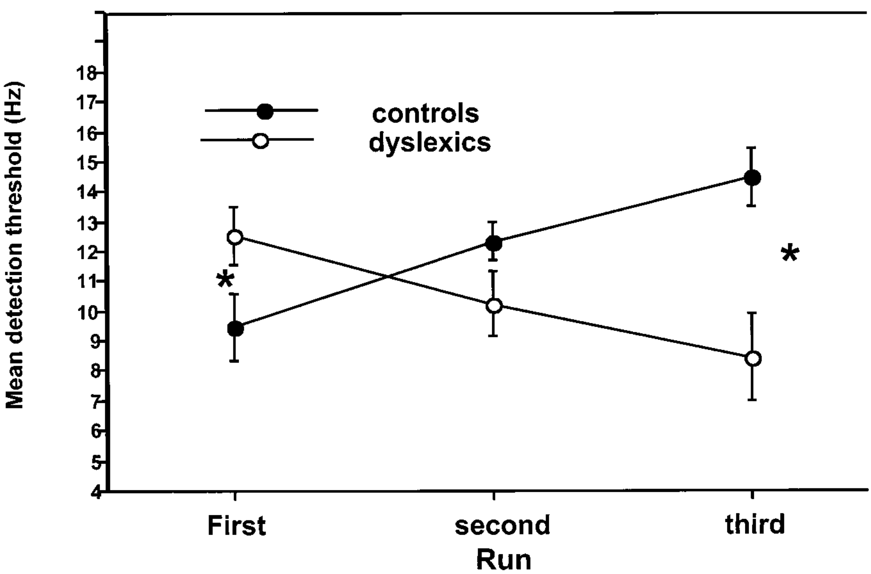

FIG. 3. Interaction of Group and Run in Experiment 2: Performance of dyslexics deteriorates progressively, while performance of controls improves progressively: *y* axis: mean detection threshold of F2 modulation rate (Hz). Significant difference between groups is indicated by *.

DISCUSSION

In this study, university students with and without DD did not differ in their performance on a linguistic (phoneme identification) task. The two groups did show significant differences in their performance on the F2 rate change detection task, with the control participants showing practice effects and the dyslexics showing fatigue effects. Also, the was a significant negative correlation in the dyslexic group between the first (phoneme identification) and second (formant rate change detection) experiment, suggesting that those who performed better on the first (linguistic) task performed worse on the second (nonlinguistic) task. These findings can be interpreted as supporting the central auditory processing deficit (CAPD) hypothesis of the etiology of DD, as they suggest that the dyslexics were processing the stimuli in the nonlinguistic task differently from the controls.

The deterioration in performance among the dyslexics may be interpreted in terms of resource depletion. Presumably, both the linguistic and nonlinguistic tasks were more difficult for the dyslexics than for the controls; nevertheless, the dyslexics may have initially managed to perform the phonemic identification task as well as the controls, and the first run of the rate change detection task better than the controls, by exerting greater mental effort and by using various compensatory mechanisms to optimize performance. However, due to resource depletion, they were unable to continue to perform with such high effort level. Indeed, many of the dyslexics indicated that they felt exhausted after performing the tasks. None of the control participants expressed this feeling.

An alternative account is that the deterioration in performance in the dyslexics may be related to frontal lobe dysfunction. Individuals with DD have been reported to evince abnormalities in selective and sustained attention, shifting attention, orienting and focusing, inhibition of routinized responses and interference, set maintenance, flexibility in generating and testing alternative hypotheses, sequential reasoning, and integration and organization of new information (e.g., Facoetti et al., 2000; Kelly et al., 1989). They have also been shown to have abnormally prolonged dwell time (Hari et al., 1999) and unusually long recovery time from aftereffects of neural activity following sensory stimulation (Di Lollo et al., 1983). Neuroimaging and neurophysiological studies also implicate the frontal lobe in DD (e.g., Robichon et al., 2000; Rippon & Brunswick, 2000; Segalowitz et al., 1992). Thus, one might argue that the fatigue effects in the dyslexics were not related to auditory or linguistic processing deficits *per se,* but rather to frontal disturbances, which may have interfered with auditory and/or linguistic processing. This explanation is in line with recent evidence suggesting that perception of auditory patterns is dependent on prefrontal processing (Griffiths et al., 2000). Furthermore, studies involving nonlinguistic visual tasks (short-term memory; vergence control across saccades) have demonstrated practice effects in normal readers and fatigue effects in poor readers (Leslie, 1975; Moores et al., 1998), implicating cross modal, or nonspecific, frontal dysfunction in DD.

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Laterality of Phonological Working Memory: Dependence on Type of Stimulus, Memory Load, and Sex

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Investigations of the laterality of phonological working memory have not always yielded consistent results. The present experiment investigated working memory for letters and numbers in two memory load conditions. In the low load condition, working memory for letters and numbers was similar. However, in the high load condition, males were more accurate at the recall of letters. This effect was not observed with numbers, in which both sexes performed more poorly. Furthermore, we observed consistent RVF advantages for both tasks, although males were more asymmetrical for the recall of letters and females were more asymmetrical for the recall of numbers. This result indicates that laterality of working memory for letters and numbers differs, and these asymmetries depend upon the sex of the participant.

INTRODUCTION

Working memory is an interactive process by which material is retrieved from stores and held in consciousness for analyses. Baddeley (1986; 1996) has proposed a model of working memory that incorporates separate processing systems for phonological materials and spatial materials. That is, it appears that verbal information is held in a store for processing that is separate from that of spatial information. The laterality of these phonological stores is the focus of this paper.

When phonological materials (e.g., letters or words) are presented laterally, an advantage appears for those stimuli presented in the right visual field (RVF), presumably reflecting the left hemisphere's language capabilities (e.g., Kimura, 1966; McKeever & Huling, 1971). When spatial materials (e.g., dot location) are presented laterally, an advantage appears for those stimuli presented in the left visual field, presumably reflecting the right hemisphere's spatial capabilities (Kimura, 1969). However, neither of these tasks require the participant to hold information in working memory.

When tasks require phonological materials (typically words, letters, or numbers) to be held in working memory, a number of apparently inconsistent results appear. For instance, Eustache et al. (1995) reported that phonological working memory was associated with increased metabolic rate in the *right* hippocampus. Vol'f (1996) reported that a LVF advantage for phonological working memory was observed in a task requiring the manipulation of number information. Furthermore, this effect was particularly pronounced in female participants when the memory load was relatively high (V'olf, 1996). The present experiment is an attempted replication and extension of this work, as we propose to study the laterality of phonological working memory for letters and numbers. We do not anticipate that letters and numbers should produce differential effects, as they are both result in phonological processing (Davidson et al., 2000).

METHODS

Participants and Procedure

The participants were 95 introductory psychology students at the University of Saskatchewan (46 males, 49 females). Participants received course credit in exchange for their participation. They had a mean age of 19.45 years ($\pm$ 2.12 *SD*), all spoke English as their first language, and all were right-handed as assessed by questionnaire.

Tasks and Procedure

Participants performed two tasks requiring numbers to be held in working memory (Working Memory for Numbers), followed by two tasks requiring letters to be held in working memory (Working Memory for Letters). The order of the two tasks was counterbalanced among participants.

Practice trials. Before starting the working memory trials, participants completed 10 practice trials to familiarize themselves with providing vocal responses. All tasks were administered via a Pentium class computer interfaced with a 19'' SVGA monitor. Participants responded vocally into a microphone and the computer recorded the delay between the onset of the presentation of the stimulus and the vocal onset latency for each response. The experimenter recorded the response of the participant or indicated that the trial was spoiled. A spoiled trial included trials in which the participant did not initially provide an acceptable response (e.g., 'umm' or a cough).

Working memory for numbers. Participants were presented with either a single number (4; load = 1) or a vertical list of 5 numbers (1, 2, 5, 7, 8; load = 5) and told to memorize them. The numbers were presented centrally in white typeface on a black background. Participants were instructed that a number would be briefly presented (100 ms, followed by a black screen) to either the left visual field (LVF) or the right visual field (RVF) of the computer screen. Participants responded ''yes'' if the number presented was one that they were to remember, and ''no'' if it was not. Participants responded as quickly as they could, without sacrificing accuracy. Between trials, participants maintained central fixation at the +. For load = 1, there were 20 trials (10 in the RVF, 10 in the LVF), with 50% of the trials requiring the answer to be ''yes'' and 50% of the trials requiring the answer to be ''no'' (foils were 1, 2, 6, 9, and 0). For load = 5, there were 20 trials (10 in the RVF, 10 in the LVF), with 50% of the trials requiring the answer to be ''yes'' and 50% of the trials requiring the answer to be ''no'' (foils were 3, 4, 6, 9, and 0).

Working memory for letters. Participants were presented with either a single letter (*d;* load = 1) or a vertical list of 5 letters (*a, b, e, g, h;* load = 5) and told to memorize them. The presentation and procedure was the same as Working Memory for Numbers. For load = 1, the foils were *a, b, f, i,* and *j,* and for load = 5 the foils were *c, d, f, i,* and *j.*

RESULTS

Working Memory for Numbers and Letters: Accuracy

A 2 × 2 × 2 × 2 repeated-measures ANOVA was performed on the accuracy of the participant's responses, using memory load (load = 1 or load = 5), visual field (RVF or LVF), and type of stimulus (letter or number) as within-subjects measures and sex (male, female) as a between-subjects measure. Results indicated that there were three significant three-way interactions: visual field by memory load by type of stimulus, $F(1, 93) = 52.15$, $p < .05$; visual field by type of stimulus by sex, $F(1, 93) = 2.90$, $p < .05$; and memory load by type of stimulus by sex, $F(1, 93) = 3.55$, $p < .05$. There was also a significant two-way interaction between memory load and type of stimulus, $F(1, 93) = 42.552$, $p < .05$. There were no other significant interactions observed.

For the visual field by memory load by type of stimulus interaction, post hoc analyses (Tukey's) indicated that for load = 1, there were no significant differences in accuracy between numbers and letters for either visual field (letter RVF $X = 92.42 \pm 10.59$ *SD;* letter LVF $X = 90.53 \pm 10.95$ *SD;* number RVF $X = 92.00 \pm 10.58$ *SD;* number LVF $X = 91.79 \pm 9.99$ *SD*), whereas for load = 5 letters were significantly more accurately reported than were numbers, regardless of the visual field (p values $< .05$ for all comparisons; letter RVF $X = 86.42 \pm 12.63$ *SD;* letter LVF $X = 85.16 \pm 12.19$ *SD;* number RVF $X = 78.63 \pm 15.06$ *SD;* number LVF $X = 74.74 \pm 14.28$ *SD*). As well, it appeared that for both numbers and letters the change from load = 1 to load = 5 resulted in a predictable and significant decrease in accuracy (p values $< .05$ for all comparisons). Of importance, the only significant difference between the visual fields was a significant increase in accuracy in the RVF for numbers in the load = 5 condition. Thus it appears that although working memory for numbers and letters behaved similarly in the load = 1 condition, in the load = 5 condition working memory for numbers was different from working memory for letters, resulting in poorer performance—especially when the numbers were presented to the LVF.

For the visual field by type of stimulus by sex interaction, post hoc analyses (Tukey's) indicated that accuracy was the poorest in the LVF when comparing within stimulus type ($p < .05$; Fig. 1). Regardless of the field of presentation, letters were performed significantly more accurately than were numbers ($p < .05$). However, for

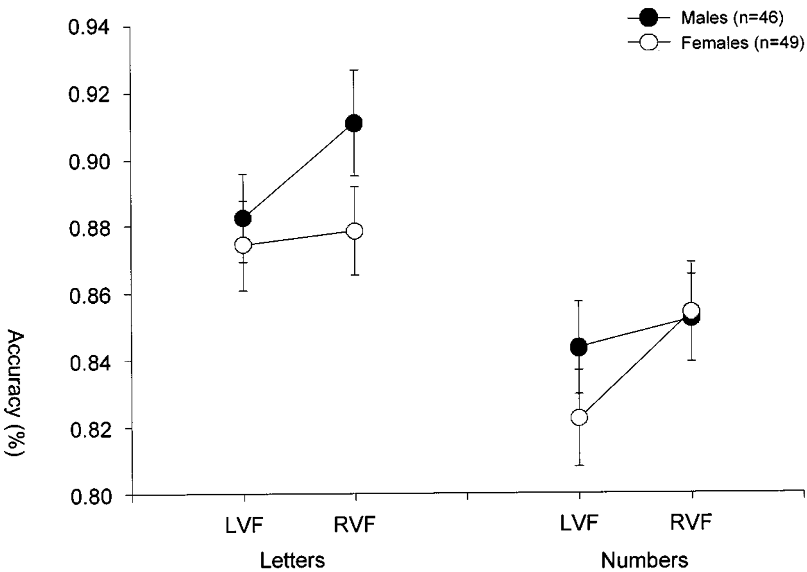

FIG. 1. The significant 3-way interaction (visual field by type of stimulus by sex interaction) for the accuracy of working memory for letters and numbers. Values are means ± SEM.

numbers the visual field advantage was only significant for comparisons between females ($p < .05$), whereas for letters the visual field advantage was only significant for comparisons between males ($p < .05$). Thus, working memory for letters and numbers appeared to differ—as participants were significantly less accurate with numbers than with letters. Furthermore, accuracy was enhanced when either numbers or letters were presented in the RVF, although this asymmetry was dependent upon the sex of the participant and type of stimulus (Fig. 1).

For the memory load by type of stimulus by sex interaction, post hoc analyses (Tukey's) indicated that accuracy was the poorest when load = 5, regardless of the type of stimulus ($p < .05$; Fig. 2). Furthermore, for load = 5, letters were performed

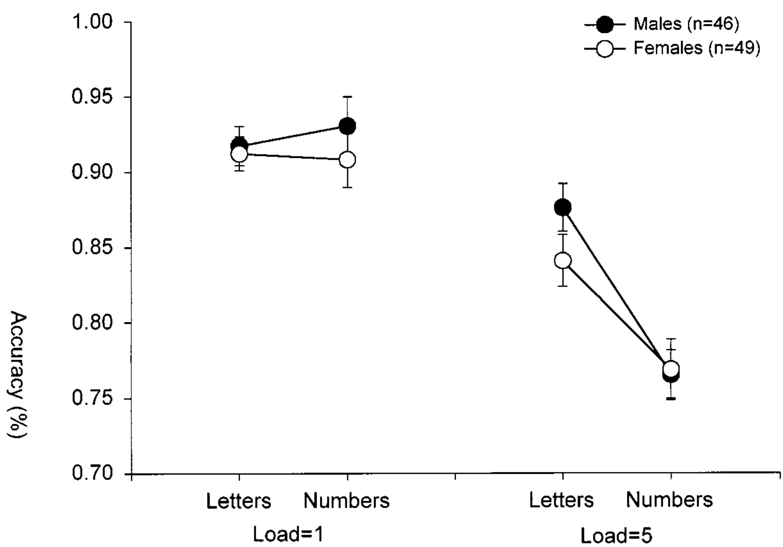

FIG. 2. The significant 3-way interaction (memory load by sex interaction) for the accuracy working memory for letters and numbers. Values are means ± SEM.

significantly more accurately than were numbers ($p < .05$), which was not observed when load = 1. For letters, males were significantly more accurate than females in the load = 5 condition.

Working Memory for Numbers and Letters: Vocal Onset Latency (VOL)

A $2 \times 2 \times 2 \times 2$ repeated-measures ANOVA was performed on the VOL for correct responses, using memory load (load = 1 or load = 5), visual field (RVF or LVF), and type of stimulus (letter or number) as within-subjects measures and sex (male, female) as a between-subjects measure. As only the correct responses were analyzed, the five 5 men who performed at chance levels on the task were excluded from this analyses. Results indicated that the only significant effects were a main effect of load, $F(1, 88) = 133.17$, $p < .05$, and a main effect of sex, $F(1, 88) = 3.88$, $p < .05$. There were no other significant effects observed. Post hoc analyses (Tukey's) indicated that men ($t = 819.56$ ms $\pm$ 149.73) responded significantly faster than did women ($t = 887.54$ ms $\pm$ 169.78), and that responses were made more quickly in the load = 1 condition ($t = 728.20$ ms $\pm$ 182.10) than in the load = 5 condition ($t = 984.23$ ms $\pm$ 206.11).

DISCUSSION

We found that working memory for letters and numbers appeared to behave similarly when the memory load was relatively small, but when the memory load was increased—the accuracy of working memory for numbers decreased. Furthermore, this effect was pronounced in the LVF, suggesting that the right hemisphere was disadvantaged for processing phonological materials. However, the sex of the participants was a factor in these visual field advantages. Unlike V'olf (1996), we did not find that these asymmetries were always more pronounced in females. For instance, males demonstrated greater asymmetries in working memory for letters, whereas females demonstrated greater asymmetries in working memory for numbers.

These differences in asymmetry are not easily attributable to any one factor. Our data suggest that working memory for numbers and letters behaves similarly in the load = 1 condition. The differences appear in the load = 5 condition, in which working memory for letters—but not numbers, resulted in poorer performance by females. Thus, working memory for letters and numbers appeared to differ, and this difference was dependent upon the sex of the participant. Interestingly, Davidson et al. (2000) observed that men were more strongly lateralized than women, whereas Ragland et al. (2000) found that the association between performance on the working memory task and cerebral blood flow in the left temporal pole was observed only in their female participants. As such, future investigations might focus on the interactions between sex, memory load and the type of phonological stimuli.

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Visual Object Agnosia as a Problem in Integrating Parts and Part Relations

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Current models of vision generally assume that the recognition of visual objects is achieved by encoding their component parts, as well as the spatial relations among parts. The current study examined how the processing of parts and their configurations may be affected in visual agnosia due to brain damage. Both a visual agnosic patient (AR) and healthy control subjects performed a visual search task in which they had to discriminate between targets and distractors that varied according to whether they shared their parts and/or their configuration. The results show that AR's visual search rates are disproportionally slow when targets and distractors share the same configuration than when they have different configurations. AR is also found to be disproportionately slow in discriminating targets and distractors that share identical parts when the targets and distractors share the same configuration. With differently configured targets and distractors, AR shows no part sharing effect. For controls, in contrast, the part and configuration sharing effects occur independently of one another. It is concluded that AR's object recognition deficit arises from difficulties in discriminating objects that share their configuration, and from an abnormal dependency of part information processing upon object configuration.

INTRODUCTION

Several studies examining visual agnosia in brain damaged individuals indicate that the visual similarity among objects is a crucial factor affecting their object recognition performance. Indeed, the errors committed by many visual agnosic patients tend to be greater for categories of objects that have high levels of within-category similarity (e.g., Humphreys, Riddoch, & Quinlan, 1988). One form of visual similarity that has been demonstrated to affect performance in visual agnosic patients is the degree to which objects share shape features. Arguin, Bub, & Dudek (1996), for instance, showed that visual agnosic patient ELM has disproportionate shape recognition difficulties in conditions that require the processing of conjunctions of shape features relative to when a single feature is sufficient. However, the stimuli used in these studies were 2D blobs, hence structurally simpler than most real world objects, which are three-dimensional and subjectively composed of multiple distinct parts. According to Biederman (1987), the latter, more complex stimuli pose particular problems for the visual system in that they must be segmented into their defining parts, which requires in turn the coding of the spatial relationships among those parts.

Although empirical support for this proposal has been reported in studies involving neurologically intact observers, little is known about how the processing of parts and part relations in multi-part objects are affected by visual recognition impairments due to brain damage.

This study examined the effects of object-parts and part-relations overlap on shape discrimination performance in an agnosic patient (AR) and matched controls. Participants performed a visual search task involving complex objects composed of multiple volumetric 3D shapes similar to Beiderman's (1987) geons. The subjects' reaction time to detect a target was examined as a function of set size in conditions where target-distractor similarity was varied according to whether the target shared its parts and/or part configuration with distractors.

METHODS

Case Description

AR was a 19-year-old woman who sustained right temporal lobe and left inferotemporal lobe damage due to a viral encephalitis she had contracted at the age of nine (see Schiavetto, Décarie, Flessas, Geoffroy, & Lassonde, 1996, for a detailed report). Her visual recognition problems involved difficulties in recognizing objects (notably animals, fruits, and vegetables), faces, and colors. These visual deficits were not due to primary visual encoding deficits, since she scored within the normal range on tests of visual acuity, visual matching, and spatial localization. She also performed normally on standardized language and verbal intelligence tests. Her agnosia for objects, faces, and colors has been shown to persist over time (see Schiavetto et al., 1996, for details).

Control Subjects

A group of 10 healthy subjects matched in terms of age to AR served as controls.

Materials

The complex 3D objects were created by combining sets of geon-like basic volumetric 3D shapes (stimuli rendered by ray-tracing; Fig. 1). The basic shapes varied along five distinct dimensions: elongation (ratio of major/minor axis; elongated vs thick), curvature of major axis (straight vs curved), tapering along main axis (tapered

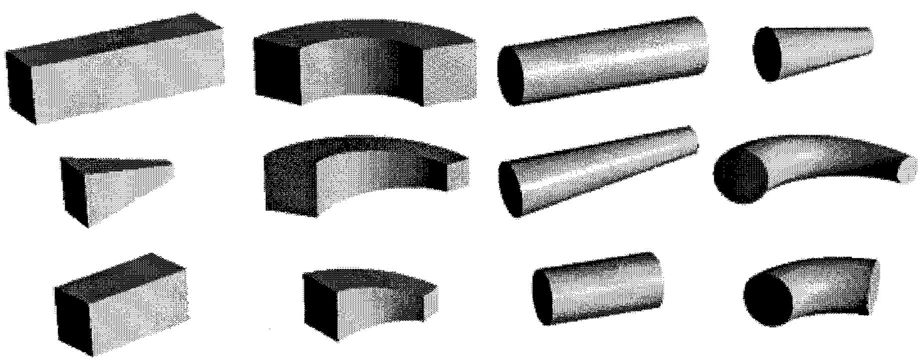

FIG. 1. The geon stimuli that were used to construct the multi-part objects in the Experiment.

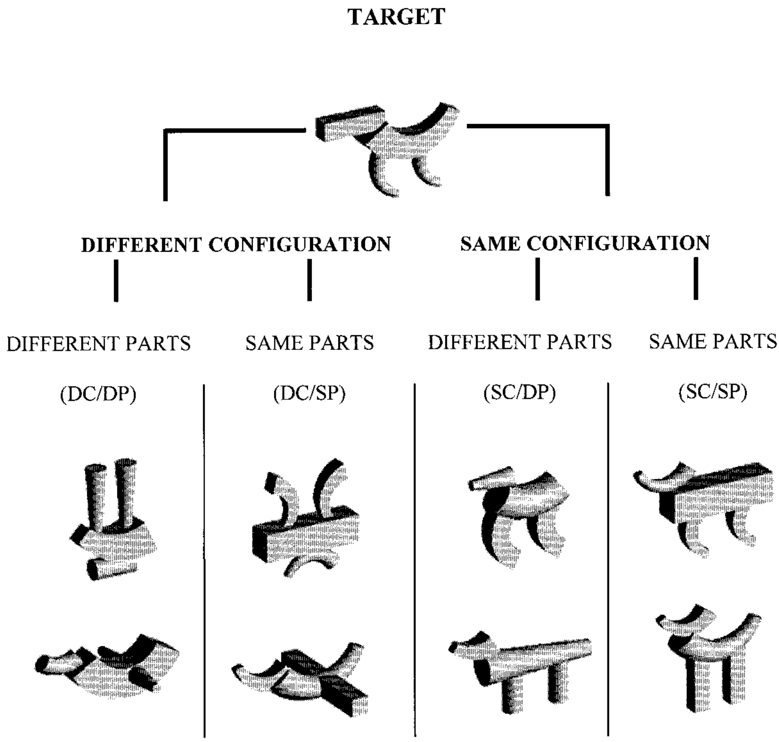

FIG. 2. Illustrations of the multi-part objects used in the different conditions of the present experiment. An example of a target (resembling a four-legged animal) is shown above, along with its corresponding distractors (shown below) for the Different configuration/Different parts (DC/DP), Different configuration/Same parts (DC/SP), Same configuration/Different parts (SC/DP), and Same configuration/Same parts (SC/SP) conditions. The other two targets that were used in the experiment are illustrated as distractors in the Different configuration/Different parts condition.

vs not), shape of cross-section (symmetric vs not), and symmetry of cross-section (symmetric vs not).

The multi-part objects were made of three basic shapes connected to one another in three highly distinct spatial arrangements. Three different objects (resembling either a four-legged animal, a bird, or a plug) served as targets throughout the experiment. These targets were combined with different sets of distractors according to the following four search conditions (Fig. 2): the targets and distractors shared neither their parts, nor their spatial arrangement (different configuration/different parts, or DC/DP); the targets and distractors did not share any of their parts, but had the same spatial arrangement (different configuration/same parts, or DC/SP); the targets and distractors shared their configuration, but differed in terms of their parts (same configuration/different parts, or SC/DP); the targets and distractors shared both their configuration and their parts (same configuration/same parts, or SC/SP).

PROCEDURE

Each subject completed a block of 160 trials for each of the 12 target-distractor sets. There were four levels of display size that varied randomly across trials (displays were made of 3, 5, 7, or 9 items). In each block, there were 20 target-present (positive) and 20 target-absent (negative) trials for each display size. On each trial, the number of instances of each distractor was equated as much as possible. Conditions were distributed in a random order within each block.

On each trial, a 500-ms asterisk (Geneva print 24) was presented at the center of a monitor, followed immediately by the search display, which remained visible until the subject responded. The targets and distractors were randomly presented at 1 of 12 equally spaced locations on an imaginary circle of 9.5° in diameter centered on the fixation point. There was a 1-s intertrial interval. Block order was random across subjects.

Subjects were instructed to respond as quickly and as accurately as possible by pressing with the index finger of the left or right hand a key on the left or right side of a computer keyboard, depending on whether they thought the target was present or absent.

RESULTS

Outlier response times (RT's) were removed from each subject's data set if they were more than three standard deviations away from the subject's mean RT within each condition. This resulted in the removal of less than 1% of the data points for either AR or the control subjects. Errors were not analyzed because they accounted for less than 1% of the data for either AR or the control subjects. Figure 3 shows

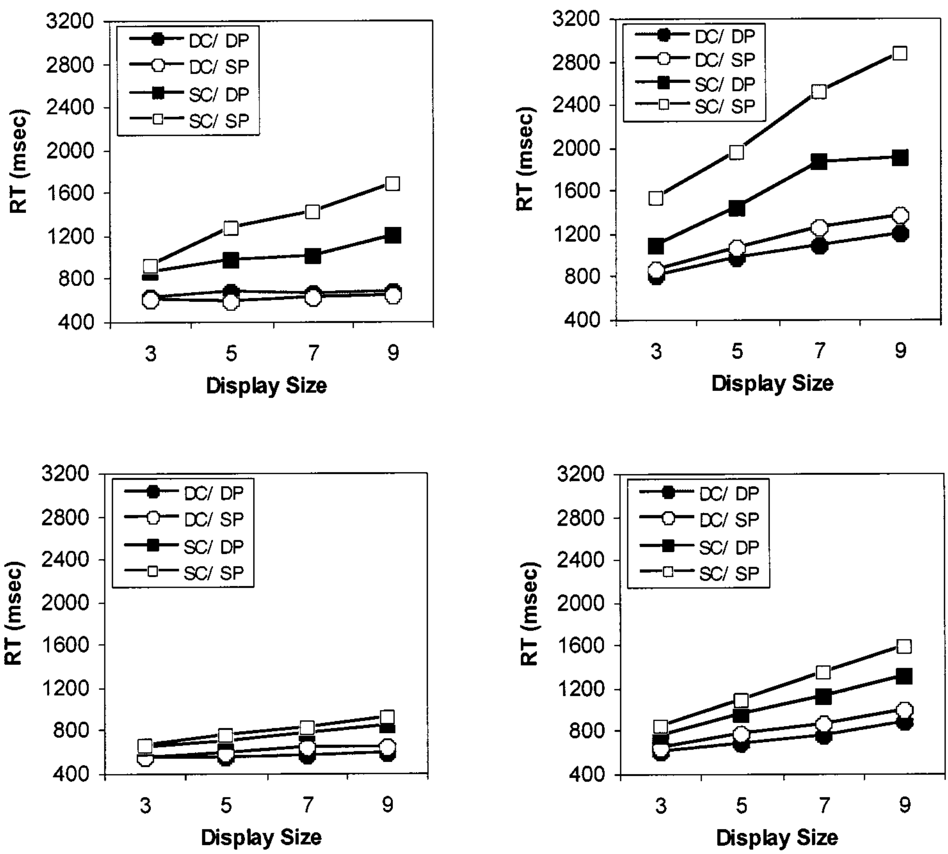

FIG. 3. Average correct RTs as a function of display size on target-present and target-absent trials for the DC/DP, DC/SP, SC/DP, and SC/SP conditions: (top) agnosic patient, (left) target present, (right) target absent; (bottom) control subjects, (left) target present, (right) target absent.

the average correct RT's for AR and the control subjects as a function of display size for each search condition. Table 1 displays the results of the linear regression analyses of RT's as a function of display size and the positive/negative slope ratios for each condition.

Separate analyses were performed on AR's and the control subject's correct RT's. Each of these analyses included a three-way ANOVA including the factors of Target presence (present vs absent), Target–distractor similarity (DC/DP; DC/SP; SC/DP; SC/SP), and Display size (3, 5, 7, 9). For both AR and normal controls, there were main effects of Target presence [AR: $F(1, 1816) = 575.3$, $p < .01$; Controls: $F(1, 9) = 52.6$, $p < .01$], Target–distractor similarity [AR: $F(3, 1816) = 317.2$, $p < .01$; Controls: $F(3, 27) = 40.3$, $p < .01$], and Display size [AR: $F(3, 1816) = 89.7$, $p < .01$; Controls: $F(3, 27) = 53.8$, $p < .01$]. The two-way interactions of Target presence × Target-distractor similarity size [AR: $F(3, 1816) = 21.5$, $p < .01$; Controls: $F(3, 27) = 13.4$, $p < .01$], Target presence × Display [AR: $F(3, 1816) = 20.8$, $p < .01$; Controls: $F(3, 27) = 29.1$, $p < .01$], and Target–distractor similarity and Display size [AR: $F(9, 1816) = 11.4$, $p < .01$; Controls: $F(9, 81) = 17.4$, $p < .01$] were also significant. Whereas the three-way interaction of Target presence × Target–distractor similarity × Display size was not significant for AR [$F(9, 1816) = 0.9$, n.s.], it was significant for the control subjects [$F(9, 81) = 4.8$, $p < .01$]. These analyses were followed up by planned comparisons that contrasted display size effects across pairs of search conditions separately for target-present and target-absent trials.

For the control subjects, the display size effect significantly differed across all pairs of search conditions (all p's $< .05$), with the DC/DP conditions producing the smallest display size effect, followed in increasing order by the DC/SP, SC/DP, and SC/SP conditions.

For AR, the effect of display size in the DC/DP and DC/SP conditions did not significantly differ for either the target-present or target-absent trials, [both p's $> .1$]. However, for the target-present and target-absent trials, both the DC/DP and DC/SP conditions produced significantly smaller effects of display size than either the SC/DP or SC/SP conditions (all p's $< .05$). The difference in display size effect

TABLE 1
Linear Regressions of Correct RTs as a Function of Display Size for Positive and Negative Trials for AR and Control Subjects

	AR						
	Positive trials			Negative trials			Pos/Neg
Condition	Intercept	Slope	R-Squ.	Intercept	Slope	R-Squ.	Ratio
DC/DP	612.2	8.1	0.70	614.9	66.8	0.99	0.12
DC/SP	568.2	7.5	0.90	630.1	84.6	0.99	0.10
SC/DP	698.1	52.1	0.92	721.1	142.4	0.92	0.37
SC/SP	589.4	121.6	0.98	837.4	229.1	0.99	0.50
	Controls						
	Positive trials			Negative trials			Pos/Neg
Condition	Intercept	Slope	R-Squ.	Intercept	Slope	R-Squ.	Ratio
DC/DP	520.6	7.1	0.98	459.1	44.5	0.98	0.16
DC/SP	496.8	17.4	0.91	476.2	57.1	0.99	0.30
SC/DP	528.7	34.1	0.99	485.2	91.9	0.99	0.37
SC/SP	545.8	40.9	0.99	474.4	123.4	0.99	0.30

between the SC/DP or SC/SP conditions was significant for target-absent trials ($p < .05$), and marginally significant for target-present trials ($p < .07$).

The linear regression analyses (see Table 1) indicate linear effects of display size in each condition. The control subjects showed evidence for preattentive search in the DC/DP condition, with a slope of correct response times as a function of display size on positive trials that is under 10 ms/item. In the other conditions, slopes are greater and the positive/negative slope ratios approach 0.5, thus indicating a serial self-terminating search (Snodgrass & Townsend, 1980).

For AR, both the DC/DP and DC/SP conditions produced slopes under 10 ms/item, thus suggesting preattentive search. However, for the SC/DP and SC/SP conditions, slopes on positive trials for AR are substantially greater and the positive/negative slope ratios are close to 0.5, which indicates a serial self-terminating search. It should be underlined that whereas AR shows a null part sharing effect with different-configuration target–distractor sets, this effect is largely magnified relative to normal controls for same-configuration target–distractor sets.

DISCUSSION

The present study shows that the visual search rates for multi-part objects are jointly affected by parts and part relations in both AR and control subjects. For all subjects, the search rates are faster when the target and distractors have different configurations than when they share configurations. However, AR produces substantially larger search slopes than control subjects for targets and distractors that have the same configuration. Another difference between AR and the control subjects, concerns the relative magnitude of the part sharing effect across the different-configuration and same-configuration target–distractor sets. Whereas the control subjects were slower at detecting targets that shared their parts with distractors irrespective of whether targets and distractors shared their configurations, AR failed to show such a part sharing effect across conditions in which the targets and distractors differed in their configurations. In other words, AR differed from normal controls in that she showed: (1) an exaggerated configuration sharing effect; (2) a largely magnified cost of part sharing between the target and distractors only when these items had the same configuration; (3) but no cost of part sharing with target–distractor sets of different configurations. It is concluded from these results that AR's object recognition deficit arises from a difficulty in discriminating objects that share their configuration and from an abnormal dependency of part information processing upon object configuration.

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Not All Triads Are Created Equal: Further Support for the Importance of Visual and Semantic Proximity in Object Identification

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Identification deficits were investigated in ELM, a temporal lobe stroke patient with category-specific deficits. We replicated previous work done on FS, a patient with category specific deficits as a result of herpes viral encephalitis. ELM was tested using novel, computer generated shapes that were paired with artifact labels. We paired semantically close or disparate labels to shapes and ELM attempted to learn these pairings. Overall, ELM's shape–label confusions were most detrimentally affected when we used labels that referred to objects that were visually and semantically close. However, as with FS, ELM had as many errors when shapes were paired with the labels ''donut,'' ''tire,'' and ''washer'' as he did when they were paired with visually and semantically close artifact labels. Two explanations are put forth to account for the anomalous performance by both patients on the triad of donut–tire–washer.

INTRODUCTION

The observed dissociation in object identification in patients with category-specific visual agnosia (CSVA) is a frequently discussed phenomenon in neuropsychology. Most patients with CSVA present with a selective impairment in the ability to correctly identify living objects (e.g., lion and tiger) yet are able to correctly identify nonliving objects (e.g., windmill and cannon). One theory that attempts to account for this dissociation is that proposed by Humphreys, Riddoch, and Quinlan (1988) and more recently by Forde, Francis, Riddoch, Rumiati, and Humphreys (1997). Central to this theory is the proposition that identification deficits in brain-damaged patients exist where object sets consist of members which are both visually and semantically similar. For example, wild felines such as lion, tiger, and leopard cause naming problems because they share many visual (i.e., they have fur, four legs, large teeth, etc.) and semantic (i.e., carnivorous hunters, etc.) features. Consequently, identification deficits arise due to a difficulty in activating a particular representation amongst many structurally and semantically similar exemplars.

Further support for the importance of visual and semantic proximity in category-specific visual agnosia comes from a series of studies by Dixon and colleagues (Dixon, Bub, & Arguin, 1997; Dixon, Bub, Chertkow, & Arguin, 1999) in which CSVA patients were tested. In these studies, computer generated shapes were created with well-defined, underlying shape dimensions such as curvature, thickness, and tapering. By varying these combinations of dimensions, shape sets were generated in which members were either visually close (i.e., had numerous overlapping values) or were visually distinct (i.e., had no overlapping values) (Dixon et al., 1999).

In a typical experiment using this *ELM Paradigm,* the patient receives short groups of learning trials followed by short groups of test trials. This pattern of interleaved learning-then-test trials continues until a certain performance level is reached and/or a certain number of trials have been completed. On learning trials, shapes are presented one at a time along with a verbal label. On test trials the shape is presented by itself, and the patient is asked to provide the appropriate label that was previously paired with that particular shape. Previous research revealed that for visually similar shape sets with multiple overlapping values, patients generally perform much better on trials where shapes were paired with semantically disparate labels (e.g., ‘‘helicopter,’’ ‘‘photocopier’’) than semantically similar labels (e.g., ‘‘ robin,’’ ‘‘crow’’). By manipulating the visual proximity of the blobs and the semantic proximity of the labels, one can independently assess the role of object form and object meaning in object identification. Using this paradigm Dixon and his colleagues (Dixon et al. 1997, 1999) showed that objects that were both visually similar AND semantically similar posed preferential object identification deficits with CSVA patients.

In previous research (Schweizer, Dixon, Westwood, & Piskopos, in press), FS, a patient with category-specific deficits as a result of herpes viral encephalitis, was tested using the ELM paradigm. The triad that paired shapes to visually and semantically disparate artifact labels (‘‘bell,’’ ‘‘eraser,’’ and ‘‘cane’’) led to significantly fewer errors than the triad that was visually and semantically close (‘‘banjo,’’ ‘‘violin,’’ and ‘‘guitar’’). This result was consistent with previous research done by Dixon and colleagues. A third triad was included by Schweizer et al. (in press), containing visually close but semantically disparate artifact labels (‘‘donut,’’ ‘‘tire,’’ and ‘‘washer’’). It was hypothesized that these items should have led to an error rate that fell between those of the two previously mentioned triad types. Instead, this triad led to as many errors as the visually and semantically close set, a finding that may suggest that the visual similarities of the objects referenced by the labels may be of greater importance than the semantic differences between those objects.

The current experiment is an attempt to more fully explore the influence of the visual and semantic overlap among objects in CSVA. More specifically, previous work by Dixon et al. (1997) revealed that the identification errors made by ELM were driven primarily by the interplay between visual and semantic proximity. It follows from this finding that ELM’s highest error rates should be in relation to labels referring to artifacts close in visual and semantic proximity (i.e., guitar, violin, banjo). To more fully test this theory and to rule out any possible anomalous findings with the single triad of donut–tire–washer, two further visually close and semantically disparate triads were employed in the present study (snorkel–cane–crowbar and spike–straw–pencil). If visual similarity is primarily responsible for the identification errors with only a minimal influence of semantics, then all three visually close and semantically disparate triads should produce relatively the same error rates as the visually and semantically close set of guitar–violin–banjo.

METHODS

Participant

ELM is a 72-year-old man who was admitted to hospital for heart failure in 1982. He was readmitted in 1985 and was found to have bilateral lesions deep in the mesio-

FIG. 1. The computer generated blob set used to test ELM.

temporal lobes. Previous testing of this patient revealed category-specific visual recognition impairments (see Arguin, Bub, & Dudek, 1996, for complete patient profile).

Stimuli

Shapes. Shape triads were generated by combining different values of curvature, thickness, and tapering. Blobs A, B, and C were all equally tapered. Blobs B and C were equally curved (1/3 the curvature of Blob A); Blobs A and B were equally thick (30 mm) and were both twice the width of Blob C (15 mm along the horizontal axis) (see Fig. 1).

Verbal Label Frequencies and Familiarity (freq, fam)

The triad of shapes shown in Fig. 1 was associated with four sets of labels. Visually close and semantically disparate artifact labels included: set 1: ‘‘donut’’(0,0), ‘‘tire’’(22,546), and ‘‘washer’’(2,0); set 2: ‘‘snorkel’’(0,0), ‘‘crowbar’’(0,0), and ‘‘cane’’(12,442); and set 3: ‘‘spike’’(2,471), ‘‘straw’’(15,508), and ‘‘pencil’’(34,598). Visually and semantically close artifact labels included: ‘‘banjo’’(2,0), ‘‘guitar’’(19,550), and ‘‘violin’’(11,468).

PROCEDURE

ELM Paradigm

Shapes were presented in the center of a computer screen one at a time accompanied by a digitized recording of their preassigned verbal label. Six learning trials were presented allowing each blob–label pairing to appear twice. After completing the learning trials, ELM was presented with six test trials consisting of the unlabeled blob appearing in the center of the computer screen. ELM was required to provide the appropriate label that was previously paired to that particular blob on learning trails. This procedure (six learning then six test trials) was repeated until 144 learning and 144 test trials were completed in each of the four shape–label conditions. Testing was conducted in four separate sessions.

RESULTS

Shape-Label Task

As illustrated in Fig. 2, ELM was able to correctly name 69% (99/144) of the visually close/semantically disparate donut–washer–tire and 72% (103/144) of the visually close/semantically close (‘‘banjo,’’ ‘‘guitar,’’ ‘‘violin’’) combinations. This difference was not significant: $\chi^2(1) = 0.18$, ns. For the other two visually close/

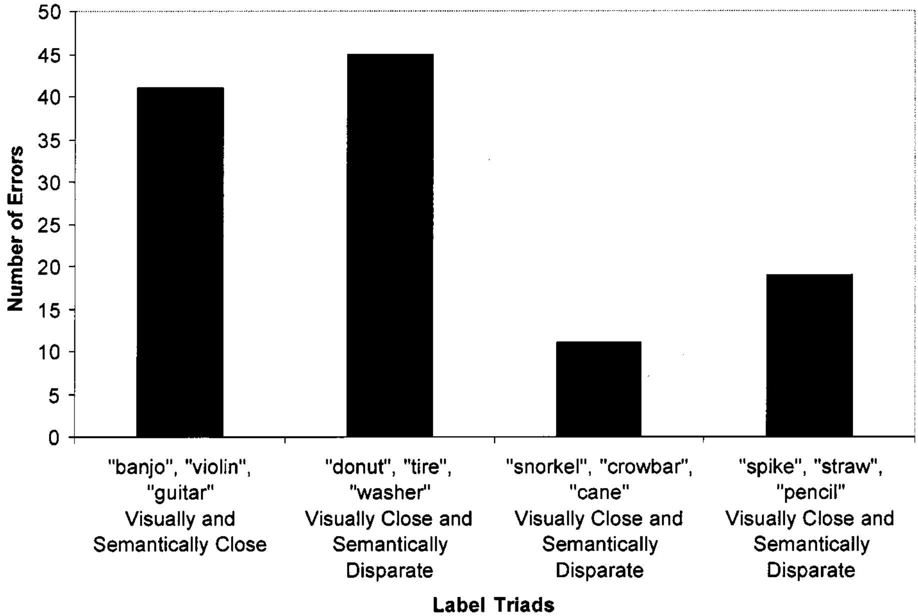

FIG. 2. ELM's error performance on the shape–label task.

semantically disparate sets, ELM was able to name 92% (133/144 for the snorkel–cane–crowbar combination) and 87% (125/144 for the spike–straw–pencil combination) of the objects correctly. This difference was also not significant: $\chi^2(1) = 2.13$, ns. The fact that ELM made a statistically equivalent number of errors on the donut–tire–washer triad as on the banjo–guitar–violin triad suggests that "donut," "tire," and "washer" may not be represented in as diffuse a psychological space as other semantically disparate categories. As expected, ELM made more errors on the visually close/semantically close combination banjo–guitar–violin than on the other two visually close/semantically disparate combinations, snorkel–cane–crowbar ($\chi^2(1) = 17.31$, $p < .001$) and spike–straw–pencil ($\chi^2(1) = 8.07$, $p < .005$). Critically, however, ELM also made significantly more errors on the visually close/semantically disparate combination donut–tire–washer than on the other visually close/semantically disparate combinations snorkel–cane–crowbar ($\chi^2(1) = 20.64$, $p < .001$) and spike–straw–pencil ($\chi^2(1) = 10.56$, $p < .001$).

DISCUSSION

We hypothesized that labels of objects with multiple overlapping visual and semantic features would cause the most identification problems for our patient, but that object labels that were visually close but semantically disparate would be associated with fewer identification problems. ELM's performance was significantly poorer on the visually and semantically close set of banjo, violin, guitar compared to the visually close and semantically disparate triads of snorkel–cane–crowbar and spike–straw–pencil. These results are consistent with our hypotheses and lend further support for the importance of the visual and semantic proximity of objects in order to fully understand category specific identification impairments. This was not, however, the case for the third visually close and semantically disparate triad. With the donut–tire–

washer triad, ELM had as many errors as with the visually and semantically close set (e.g., ‘‘violin,’’ ‘‘guitar,’’ ‘‘banjo’’).

This study replicates previous findings with patient FS where we found that performance on the visually close and semantically disparate set of donut–tire–washer was as poor as with the visually and semantically close set of banjo–violin–guitar. The ELM results confirm that the visually close but semantically disparate triad of donut–tire–washer consistently leads to patterns of data similar to triads consisting of visually and semantically close items.

There are two possible explanations to account for the anomalous performance by both patients on the triad of donut–tire–washer. One reason may be that the objects in the triad of donut-tire-washer have as their most salient feature their visual attributes (i.e., round with a hole in the middle) with relatively little semantic information to help spread the objects apart in psychological space. If this were the case it would be very difficult for patients to activate a particular representation among many visually similar exemplars with not enough semantic uniqueness to assist in disambiguation. Another possible reason is that in colloquial English a spare tire is often referred to as a ‘‘donut.’’ This similarity in meaning would make the members not only close in visual proximity but also close in semantic proximity. This reasoning was confirmed when ELM was asked to tell us everything he knew about the word ‘‘tire.’’ He replied ‘‘. . . a small spare tire is called a donut, and you can’t go over certain speeds and you can only go on short distances on it until you find a garage and change it.’’ Unfortunately, FS was unavailable to provide us with his semantic representation of ‘‘tire’’ and as such we cannot rule out that his object identification deficits are primarily a result of visual similarity with semantic similarity being of less importance.

Overall, despite the anomalous performance with the donut–tire–washer triad, ELM’s shape–label confusions were most pronounced when we used artifact labels that were both visually and semantically close. These results support our hypothesis that the interplay between visual and semantic proximity is an important determining factor for errors in object identification in CSVA patients.

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