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THE INTERACTION OF LEXICAL AND SUBLEXICAL PROCESSES IN READING, WRITING AND REPETITION

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Abstract—It has recently been proposed that in the course of repetition, reading aloud and writing to dictation, lexical representations are activated and selected for output by the joint operation of the semantic system and of sublexical conversion mechanisms—the Summation Hypothesis [HILLIS and CARAMAZZA, *Brain Lang.* **40**, 106–144, 1991]. The hypothesis predicts that semantic errors in oral reading and in writing to dictation should only occur when both the semantic system and the sublexical component involved in that task (orthography to phonology and phonology to orthography conversion, respectively) are damaged. The performance of Italian patient E.C.A. indicates damage to the semantic system, and to sublexical phonology to phonology and phonology to orthography conversion mechanisms, but with substantial sparing of sublexical orthography to phonology conversion processes. In agreement with expectations derived from the Summation Hypothesis, E.C.A. produced semantic errors in repetition and in writing to dictation, but not in reading aloud. The paucity of semantic errors in speakers of languages with relatively transparent orthographies is discussed in the context of the Summation Hypothesis.

INTRODUCTION

ALTHOUGH the production of semantic errors in lexical processing tasks would seem to constitute *prima facie* evidence for damage to the semantic component of the lexical system, it has been shown that not all types of semantic errors can be attributed to such a cause. Indeed, there is strong evidence that whereas in some cases semantic errors could plausibly be assumed to result from damage to the lexical semantic component [19], in other cases they would seem to result from damage to modality-specific lexical components—the phonological or orthographic lexical components (Refs [6] and [7]; but see Ref. [15], for a discussion of alternative interpretations).

One important distinction between these two types of lexical deficits concerns the expected patterns of errors in different lexical processing tasks. On the assumption that a single semantic component mediates performance in all lexical tasks, we would expect that damage to the semantic component (and to the sublexical orthography to phonology and phonology to orthography conversion procedures) should lead to the production of semantic errors in all such tasks. However, when semantic errors arise from selective damage to the phonological or the orthographic lexicons, they should only be present in the affected modality—either only in oral production or only in spelling. These expectations have been confirmed: Patient K.E. [19] made semantic errors in roughly equal proportions in reading,

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writing, naming, and comprehension tasks; by contrast, patients H.W. and R.G.B. [6] made semantic errors only in oral production tasks, while patient S.J.D. [7] made semantic errors only in spelling tasks. These contrasting patterns of performance were interpreted as indicating damage to the semantic component in patient K.E., damage to the phonological output lexicon in patients H.W. and R.G.B., and damage to the orthographic output lexicon in patient S.J.D.

The performance in patients such as H.W., R.G.B., and S.J.D. clearly demonstrates that the production of semantic errors in some lexical processing tasks does not necessarily imply the existence of damage to the semantic component of the lexical system. However, the absence of semantic errors in one or more lexical processing tasks in a patient who produces semantic errors in other lexical processing tasks does *not* imply that the damage responsible for the semantic errors in the latter tasks cannot concern the lexical–semantic component. The reason for the latter claim is based on the assumption that in some tasks the activation of lexical–phonological and lexical–orthographic representations receives input from components of processing other than the semantic component. These nonsemantic inputs to the modality-specific lexicons could impede the production of semantic errors even if the semantic component were to be damaged. We elaborate on this point below.

A widely accepted, if not uncontroversial, hypothesis about the functional architecture of the lexical processing system distinguishes not only between autonomous phonological and orthographic lexical components but also between distinct, lexically- and nonlexically based procedures for oral reading and spelling [8, 11, 24, 29, 34]. Within this framework, HILLIS and CARAMAZZA [17, 18] (see also Ref. [26]) have presented evidence in support of a particular claim about the relationship between lexical and non-lexical procedures in reading and spelling: The Summation Hypothesis. This hypothesis (see also Ref. [33]) claims that the activation and selection of a lexical entry in the phonological and orthographic output lexicons is a joint function of semantic information and the output of sublexical orthography to phonology or phonology to orthography conversion processes, as the case may be. A schematic representation of this assumption is shown in Fig. 1.

To illustrate the implications of the Summation Hypothesis for lexical production, consider the task of oral reading—say, pronouncing the word *tulip*. We assume that the stimulus *tulip* activates the corresponding entry in the orthographic input lexicon, which in turn activates a semantic representation in the semantic component. The latter, in turn, activates maximally the phonological representation /tulip/ but also, to lesser degrees, other semantically-related entries such as, for example, /rose/, /garden/, /holland/, /carnation/, and so forth. Concurrently with this procedure for activating lexical entries in the phonological output lexicon, the stimulus *tulip* is processed by the sublexical orthography to phonology conversion mechanism. The output of this procedure feeds both to the phonological output lexicon and to the phonological buffer. The input to the phonological lexicon summates with the activation produced by the semantic input. Under normal circumstances the activation of lexical–phonological representations from the semantic component is sufficient to determine the correct output—/tulip/, in this case. In other words, the amount of information from the sublexical procedure that actually contributes to the activation of lexical forms in the normal case may be very close to zero and it depends on how fast the semantic procedure works in selecting the correct lexical form for output. In those cases where the semantic procedure is slow enough to allow input from the sublexical procedure to have an effect, the information from the sublexical procedure may only concern the initial segment of the word or other general features such as length or stress pattern.

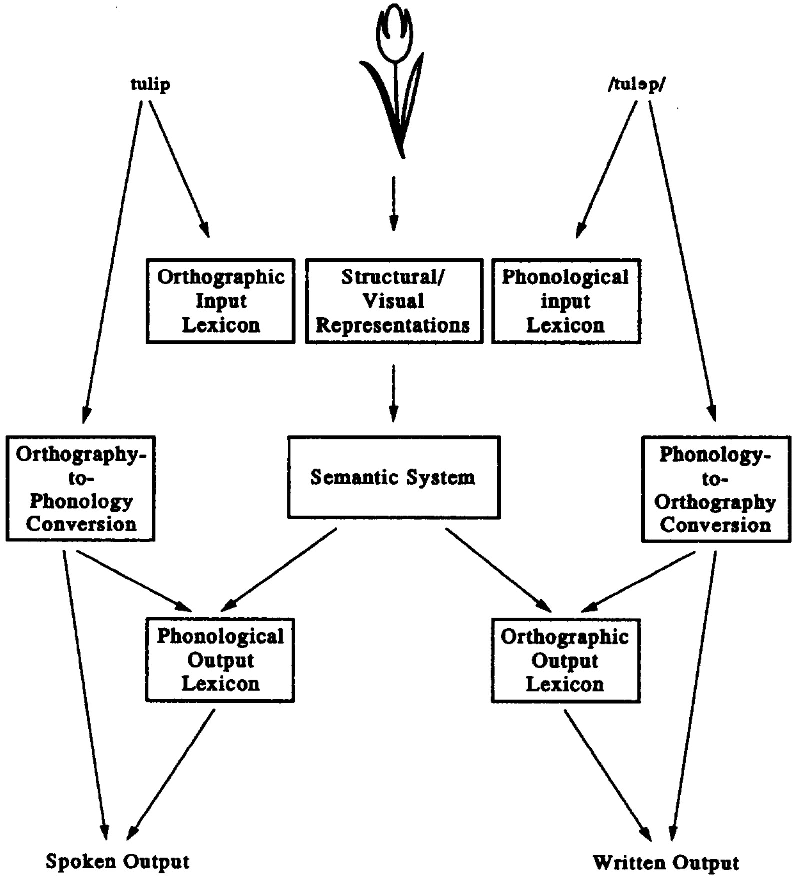

Fig. 1. Schematic representation of lexical processing system.

However, if, for whatever reason, the activation deriving from the semantic component were to be insufficient to determine the correct output, the activation deriving from the sublexical, orthography to phonology conversion procedure could help to produce the correct response.

The Summation Hypothesis proposed by HILLIS and CARAMAZZA [17] differs from a similar hypothesis proposed by MARSHALL and NEWCOMBE [23] to account for the production of semantic paralexias. MARSHALL and NEWCOMBE argued that the semantic procedure for activating lexical phonological representations is intrinsically noisy, leading naturally to semantic errors unless the response is constrained by phonological information provided by the sublexical orthography to phonology conversion procedure. One obvious prediction in this model is that normal subjects should produce a non negligible number of semantic errors in tasks such as word–picture matching and picture naming, in which the response is produced solely on the basis of information activated in the semantic system. Since this pattern of performance is not observed, we prefer to assume that the semantic procedure, unless damaged or otherwise stressed, functions flawlessly.

The Summation Hypothesis allows specific predictions about the form that damage to the cognitive system has to take in order for it to result in the production of semantic errors in tasks (reading aloud, writing to dictation and repetition) that implicate the interaction between semantic and sublexical mechanisms in lexical production. Given that lexical forms for output receive activation not only from the semantic component but also from sublexical procedures, semantic errors in a specific modality cannot be produced unless, in addition to damage to the semantic or modality-specific lexical component, the corresponding sublexical procedure is also damaged. This prediction is consistent with a number of observations in the recent neuropsychological literature. Thus, patients who produce semantic paralexias in reading aloud have been shown to have severe difficulty in reading pseudowords (e.g. cases described in Refs [6] and [10]); patients who produce semantic paragraphias in writing to dictation have been shown to have severe difficulties in spelling pseudowords (e.g. Refs [5], [7], [10] and [30]); and, patients who produce semantic paraphasias in repetition have been shown to have severe difficulties in repeating pseudowords (e.g. Refs [20] and [22]).

Here we report the performance of a patient, E.C.A., an Italian aphasic speaker, who produces semantic errors in all lexical production and comprehension tasks except reading aloud. This pattern of performance provides useful information concerning the organization of the lexical system and the contribution of sublexical procedures in reading, spelling and repetition. We will also discuss the puzzling observation that while semantic errors in transcoding tasks are not infrequent in speakers of languages with opaque orthographies (like English), they are rather exceptional in speakers of languages with transparent orthographies (for Italian, the only reported cases are those described by JOB and SARTORI [21]; MICELI, VILLA and SILVERI [28]; and for Spanish those described by RUIZ, ANSALDO and LECOURS [32]; FERRERES and MIRAVALLES [12]. We will argue that the Summation Hypothesis provides a plausible account for the paucity of semantic errors in reading and writing in languages with relatively transparent orthographies (e.g. Spanish, Italian), and for their relatively high frequency in languages with opaque orthographies (e.g. English).

CASE HISTORY

E.C.A. is a 70-year-old, right-handed man. His education includes 3 years of study at the university level. He worked as an accountant in a large food company for many years. At age 62, he was involved in a car accident, which resulted in a fractured left leg. Three days later, probably due to fat embolism, E.C.A. developed sudden right hemiparesis and aphasia. He was then referred for the first time to the Neuropsychology Service of the Catholic University in Rome. The neurological exam showed a very mild reduction of strength and a moderate hypesthesia on the right side of the body, and a mild right visual field cut. After discharge from the hospital, E.C.A. underwent speech therapy for several years. He has been followed as an outpatient at somewhat irregular intervals. A CT-scan performed approximately one year post onset demonstrated a hypodense area in the left hemisphere, involving the entire temporal lobe (except for the tip) and the parietal lobe adjacent to it. The lesion also extended into the temporo-parietal white matter structures. The present study was carried out when E.C.A. was approximately 7 years post onset, between July 1989, and July 1991.

The neurological exam carried out at the beginning of the present study showed no central motor or auditory deficits. E.C.A. complained of occasional paresthesias on the right arm, as well as reduced sensitivity to extreme heat and cold. He also complained of occasional reduction of peripheral vision on the right, but no visual field defects could be demonstrated.

Neuropsychological exam

E.C.A. obtained normal scores in tasks exploring buccofacial and limb praxis, and constructional praxis. Verbal and nonverbal agility were normal. Performance on Raven's Colored Progressive Matrices was also within normal limits. Performance on visuo-perceptual tasks was accurate. Calculation and number processing were mildly impaired.

In memory probe tasks, E.C.A. obtained normal scores with series of 4, 6 and 8 words, and scored mildly but clearly below normal with series of 4 and 6 pseudowords. Reproduction tasks, requiring the ability to repeat series of words and pseudowords, were severely impaired: E.C.A. produced correctly only 2/10 series of two bisyllabic words, and 0/10 series of two bisyllabic pseudowords.

Language processing tasks

In March 1989, E.C.A. was submitted to a screening battery for aphasia [27] and other tasks designed to assess the nature of his language disorder.

Tasks exploring sentence processing. E.C.A.'s speech was fluent and contained a large variety of grammatical constructions, including subordinate sentences, but was marred by lexical, semantic, morphological and phonological errors. His spontaneous writing demonstrated similar features, except that spelling errors were observed instead of phonemic substitutions.

E.C.A. performed poorly on grammaticality judgement tasks: 39/48 (81.3%) correct for aurally presented stimuli and 16/24 (66.7%) correct for visually presented stimuli. His sentence comprehension ability was also impaired. In the auditory version of a sentence/picture matching task, E.C.A. responded correctly to 51/60 (85%) sentences. He incorrectly chose 4/20 thematic role reversal alternatives, 2/20 morphological alternatives (e.g. singular for plural), and 3/20 semantic alternatives (e.g. boy for girl, or caress for hug). In the visual version of the task, E.C.A. responded correctly in 39/45 (86.7%) cases. He made four role reversal and two semantic errors. E.C.A.'s performance in these tasks suggests that he has a semantic deficit and possibly also a syntactic deficit.

Tasks exploring lexical processing. In an auditory lexical decision task, E.C.A. produced 602/640 (94.1%) correct responses, indicating a mild but clearly pathological level of performance. The majority of the errors were false alarms (30/320). Abstract/concreteness and grammatical class did not significantly affect performance in this task. In two out of three sublists controlled for frequency, performance was identical on high- and low-frequency stimuli. In the third list, a mild frequency effect was present—E.C.A. made no errors on 80 high-frequency words, but failed to recognize as words 6/60 (7.5%) low-frequency items. E.C.A.'s lexical decision performance with visually presented stimuli [625/640 (97.7%) correct] was indistinguishable from that obtained by normal controls.

Single-word comprehension was assessed by means of auditory and visual word-to-picture matching tasks. E.C.A. was asked to match a word to one of two pictures: the correct alternative and either a semantically related, on half of the trials, or a phonemically/visually related foil, on the other half of the trials. Normal controls made no errors on this task. E.C.A.'s performance was clearly impaired with auditorially-presented stimuli: He responded correctly only in 171/186 (91.9%) trials and made errors to both semantic (9/93; 9.7%) and phonological foils (6/93; 6.5%). His performance with visually-presented stimuli (3/93 semantic errors and 1/93 phonological errors) also revealed a mild deficit.

E.C.A.'s overall correct performance in various lexical production tasks is summarized in

Table 1. A direct comparison of performance across tasks is not possible because the stimuli in these tasks were not selected with this consideration in mind. Nonetheless, it would seem that reading performance is considerably better than that obtained in the other production tasks. This impression is confirmed when we consider E.C.A.'s performance in greater detail. Table 2 summarizes the type and distribution of errors in the various tasks. A brief description of the results in each task follows.

Table 1. Correct responses produced by E.C.A. in reading aloud, writing to dictation and repeating isolated words and nonwords, and in oral and written picture naming (percentages are in parentheses)

	Words	
Reading aloud	955/1071	(89.2)
Writing to dictation	338/556	(60.8)
Repetition	1827/3060	(40.3)
Oral naming	29/120	(75.8)
Written naming	38/120	(68.3)

Table 2. Distribution of error types in reading aloud, writing to dictation and repeating words, and in oral and written naming (percentages are in parentheses)

	Reading ($n=1071$)	Dictation ($n=556$)	Repetition ($n=3060$)	Oral naming ($n=120$)	Written naming ($n=120$)
Semantic		26 (4.7)	131 (4.3)	12 (10.0)	15 (12.5)
Circumlocution		3 (0.5)	153 (5.0)		
Omission		31 (5.6)	248 (8.1)	3 (2.5)	9 (7.5)
Stress	14 (1.3)				
Morphological	23 (2.1)	34 (6.1)	339 (11.1)	2 (1.7)	2 (1.7)
Phonol/Orthogr	73 (6.8)	73 (13.1)	383 (12.5)	8 (6.7)	9 (7.5)
Morph + Ph/Orth	3 (0.3)	5 (0.9)	81 (2.6)		1 (0.8)
Unrelated Word		15 (2.7)	145 (4.7)	1 (0.8)	2 (1.7)
Others	3 (0.3)	31 (5.6)	349 (11.4)	3 (2.5)	
Total	116(10.8)	218 (39.2)	1827 (59.7)	29 (24.2)	38 (31.7)

E.C.A. was mildly impaired in oral reading (89.2% correct). Stimulus length, frequency, grammatical class, and concreteness did not affect performance. The vast majority of the errors resulted in responses that were closely related to the stimulus either phonemically/orthographically (73 or 6.8%) or morphologically (23 or 2.1%). Examples of these error types are: *regalato* (given) → /rekala'to/ (correct response: /re'galato/) and *automobile* (car) → "automobili" (cars), respectively. All the incorrect responses scored as morphologically related to the stimulus were also visually/phonemically similar to the input string. E.C.A. also produced 14 (1.3%) incorrect responses that resulted in stress assignment errors, as in *patetico* (pathetic) → /pate'tiko/ (correct pronunciation: /pa'tetiko/); five additional stress errors (0.5%) which were followed by spontaneous self-corrections were counted as correct responses. The existence of stress errors in the corpus of errors produced by E.C.A. indicates that, at least some of the time, he pronounced words by the application of sublexical orthography to phonology conversion procedures.

E.C.A. was severely impaired in repetition. He correctly produced only 1233/3060 (40.3%)

responses. As in reading, some incorrect responses resulted in phonological errors (12.5%) or in morphological errors (11.1%). He also produced responses (2.6%) that contained both a morphological and a phonological error. However, unlike performance in reading where morphologically-related incorrect responses were always also highly visually/phonemically similar to the stimulus, many morphological errors produced in repetition differed considerably from the target response (e.g., /edu'kavano/ (they were educating) → /edu'kyamo/ (we educate); /misu'ryamo/ (we measure) → /misu'rate/ (you measure, pl.); /kante'ra/ (he will sing) → /kan'tanti/ (singers)). An even more substantial contrast with performance in reading concerns the production of many semantic substitutions (e.g., "magnifici" (magnificant) → "bellissimi" (beautiful); "monaci" (monks) → "suore...no, allora il prete..., no, San Francesco..., frate" (sisters, no, then the priest..., no, Saint Francis..., brother)) and circumlocutions (e.g., "decidono" (they decide) → "ce'è una persona che dice: facciamo qualche cosa" (there is someone who says: Let's do something)). E.C.A. produced 284 (9.3%) semantically related error responses: 131 (4.3%) semantic substitutions, of which 12 also contained a phonological error, and 153 (5%) circumlocutions. He also produced a number of unrelated word responses (4.7%) and "other" (19.5%) errors, that included neologisms, fragments and omissions. Many "omissions" consisted of one or more semantically incorrect words, explicitly recognized as incorrect by E.C.A., who subsequently did not attempt further responses. Frequency and grammatical class affected E.C.A.'s repetition performance: He repeated low frequency words more poorly than high frequency words and he repeated verbs and function words more poorly than nouns. Concreteness also affected his performance: he repeated correctly 108/137 (78.8%) concrete nouns and 50/90 (55.6%) abstract nouns matched for length (3–7 letters). This effect is statistically significant ($\chi^2 = 12.823$; $P < 0.001$).

E.C.A.'s performance in writing to dictation was also very poor. He correctly produced only 338/556 (60.8%) responses. As in repetition, he produced visually/phonemically related errors (13.1%) morphologically related errors (6.1%), and errors that were both morphologically and visually/phonemically related to the target response (0.9%). E.C.A. also produced 29 (5.2%) responses that were semantically related to the stimulus: 26 (4.7%) semantic substitutions and 3 (0.5%) circumlocutions. The relatively lower incidence of semantically related errors in the writing to dictation compared to the repetition task results from the fact that many multi-word utterances were produced as responses in repetition but not in writing. Thus, in writing to dictation, E.C.A. often produced oral circumlocutions [31 (5.6%) times], but did not write them down, preferring to skip the response altogether. He also produced unrelated word responses (2.7%) and unscorable responses (11.1%). Analyses of controlled sublists demonstrated an effect of frequency (50/80 correct for high-frequency vs 31/80 correct for low-frequency words; $\chi^2 = 8.101$; $P < 0.01$) and grammatical class (29/40 correct for nouns vs 18/40, 15/40 and 20/40 correct for adjectives, verbs and function words, respectively; $\chi^2 = 10.507$; $P < 0.02$).

Oral and written naming were also impaired in E.C.A. [91/120 (75.8%) and 82/120 (68.3%) correct, respectively]. In these tasks, too, he made semantic errors (10 and 12.5%, in oral and written naming, respectively), no responses (2.5 and 7.5%, in oral and written naming, respectively), phonemically/orthographically related responses (6.7% and 7.5%, in oral and written naming, respectively), and a small number of other responses. E.C.A.'s performance was more accurate in object naming than in action naming. In matched subsets, he correctly named 45/54 (83.3%) objects and 40/66 (60.6%) actions. The effect of grammatical class was statistically significant ($\chi^2 = 6.394$; $P < 0.02$).

In all lexical production tasks, performance was affected by stimulus length. E.C.A. responded less accurately to long than to short words. Performance as a function of length is shown in Table 3.

Table 3. Incidence of incorrect responses in word production tasks as a function of length (percentages are in parentheses)

Stimulus length	Reading	Dictation	Repetition	Oral naming	Written naming
3–5	9/112 (8.0)	37/159 (23.3)	84/268 (31.3)	2/22 (9.1)	3/22 (13.6)
6–7	26/345 (7.5)	56/175 (32.0)	540/1028 (52.5)	8/45 (17.8)	12/45 (26.7)
8–9	55/465 (11.8)	107/195 (54.9)	802/1244 (64.5)	17/48 (35.4)	22/48 (45.8)
10–19	26/149 (17.4)	18/27 (66.7)	401/520 (77.1)	2/5 (40.0)	1/5 (20.0)

Tasks exploring sublexical conversion mechanisms. E.C.A. showed a very minor deficit in auditory discrimination of stop consonants in CV syllables [58/60 (96.7%) correct], but a more noticeable deficit in matching auditority- to visually-presented CV syllables [49/60 (81.7%) correct]. E.C.A.'s performance in reading, repeating, and writing 2- and 3-syllable pseudowords is shown in Table 4.

Table 4. Performance obtained by E.C.A. in nonword processing tasks (percentages are in parentheses)

	Correct responses
Reading aloud	158/187 (84.6)
Repetition	11/298 (3.7)
Writing to dictation	9/250 (3.6)

E.C.A9 was mildly impaired in reading pseudowords (84.5% correct). All the errors resulted in very near misses, bearing a close visual/phonemic resemblance to the target response. None of his incorrect responses differed from the stimulus by more than two letters (e.g., *coba* → roba (stuff); *qualerco* → gualerco). There was no tendency to produce words as incorrect responses. By contrast to the mild difficulties he encountered in reading, E.C.A. performed very poorly in writing (3.6% correct) and in repeating (3.7% correct) pseudowords. Most of the responses he produced in these tasks (84% and 80.3% in writing and repeating, respectively) bore little resemblance to the stimulus (e.g., writing: /arpi'lo/ → *armento* (flock of sheep); /ka'sere/ → *chiego*; repeating: /'katora/ → /'pretra/). In these tasks, too, E.C.A. did not show any tendency to produce words as incorrect responses.

In short, E.C.A. demonstrated a relatively preserved ability to use orthography to phonology conversion procedures (as shown by mildly impaired performance in pseudoword reading), but a severe disruption of both phonology to phonology and phonology to orthography mapping (as shown by his inability to repeat and to write to dictation pseudowords). Further evidence for E.C.A.'s effective use of orthography to phonology conversion procedures is provided by the fact that he produces stress errors in reading. Errors of this type, restricted to oral reading, clearly indicate that E.C.A. reads some words through the non-lexical orthography to phonology conversion procedure (see Ref. [25] for further discussion of this issue).

INTERIM DISCUSSION

The major characteristics of E.C.A.'s performance in lexical and nonlexical processing tasks can be summarized as follows. Word comprehension was impaired in both the auditory and the visual modality; oral and written naming were also moderately impaired; repetition and writing to dictation were severely impaired for familiar words and virtually abolished for pseudowords; and, oral reading of words and pseudowords was much better preserved than all the other word and pseudoword processing tasks.

The types of errors produced by E.C.A. also differed across tasks. In all comprehension and production tasks *except reading*, he produced semantic errors. In all production tasks, *except reading*, he produced circumlocutory responses, that were sometimes also semantically incorrect [e.g. venduto (sold) → io ho comprato (I have bought)]; other errors consisted of incomplete responses or failures to respond altogether. In all tasks *including reading*, the patient also produced morphological and phonemic/orthographic errors. In *oral reading*, but *not* in repetition or oral naming, E.C.A. produced stress assignment errors.

E.C.A.'s performance reveals a theoretically interesting pattern of dissociation and association of deficits across different lexical and non-lexical processing tasks. Specifically, there is a correlation, on the one hand, between relatively spared ability to use orthography to phonology conversion procedures and the absence of semantic errors in oral reading and, on the other hand, between impaired ability to use sublexical conversion procedures in repetition and spelling and the occurrence of semantic errors in these tasks. This pattern of performance is consistent with the hypothesis of damage to both the semantic component and to sublexical phonological and phonology to orthography conversion process in a model of lexical processing such as the one schematically depicted in Fig. 1. In oral reading, the relative sparing of orthography to phonology conversion processes effectively "blocks" the production of semantic errors that would have been produced as a consequence of damage to the semantic component.

Further support for the hypothesized form of damage accrues from the patient's performance in naming and comprehension tasks. The expectation derived from the hypothesis of damage to the semantic component in the model in Fig. 1 is that the patient should also make semantic errors in comprehension and naming tasks independent of modality of input or output. E.C.A.'s performance conformed with these expectations: He made semantic errors in auditory and visual word comprehension tasks and in spoken and written naming tasks.

Although the results reported thus far are *consistent* with the hypothesized model and the proposed form of damage to the model, they do not allow an unambiguous choice between the latter hypotheses and alternative formulations of the nature of the deficit in E.C.A. Thus, for example, the results we have reported are also consistent with the alternative hypothesis of independent damage to all modality specific components of the lexical system, in the presence of an intact semantic system. (Of course, it is possible to entertain more complex hypotheses involving damage to *both* the semantic and the modality-specific lexical components.) In the rest of this paper we will discuss further evidence that favors the hypothesis of damage to the semantic system.

Processing the same set of words in various tasks. The hypothesis of a common semantic deficit predicts qualitatively and quantitatively similar patterns of performance across all lexical processing tasks, unless the patient has suffered damage to other relevant components of processing. In the latter case, the simple fact that a patient's performance across several lexical tasks may differ does not imply that he does not have a deficit to the lexical semantic component. However, in the case where the patient's performance across tasks is, in fact, similar we would be justified in seriously entertaining the possibility of a deficit to the semantic component. We could not evaluate the latter possibility with the tasks we have reported thus far because the stimuli used in these tasks were not controlled for the variables that seemed to affect the patient's performance. Various stimulus dimensions (e.g., grammatical class, abstractness/concreteness) affected E.C.A.'s response accuracy in semantic processing tasks. However, these variables were not systematically represented and/or controlled in the previously administered lists. In this section of our report we will focus on E.C.A.'s performance in comprehension and production of 314 concrete nouns, ranging in length from three to seven letters. The stimulus words were presented to the patient in the context of the following tasks: auditory and visual comprehension, reading aloud, repetition, writing to dictation, oral naming and written naming. A subset of 54 stimuli was also administered for tactile naming. A summary of E.C.A.'s performance in these tasks is shown in Table 5.

Table 5. Correct responses produced by E.C.A. in tasks that required comprehension and production of the same 314 concrete nouns, ranging in length between 3 and 7 letters. The results obtained on a subset of 54 stimuli presented for tactile naming are also reported (percentages are in parentheses)

	Correct responses	
Auditory comprehension	247/314	(78.7)
Visual comprehension	264/314	(84.1)
Reading aloud	285/314	(90.8)
Repetition	242/314	(77.1)
Writing to dictation	253/314	(80.6)
Oral naming	230/314	(73.2)
Written naming	241/314	(76.8)
Tactile naming	41/54	(75.9)

For the purpose of this analysis, incorrect responses were scored as follows. Incorrect responses resulting in the substitution of the target with a semantically related word (e.g. banana → apple), in a circumlocution (e.g., rolling pin → you use it to make pasta), or in the failure to produce a response were scored as "semantic-type" errors. Omissions were included in this count because they always took place after one or more semantically incorrect responses. Omissions occurred frequently in the course of spelling tasks (13 times in both naming and writing to dictation, or 4.1%). In these cases, E.C.A. produced verbal circumlocutions, that he did not write, thus skipping the response altogether. Omissions were less frequent in oral tasks [none in naming, 5 (1.6%) in repetition]. In these cases, E.C.A. produced one or more incorrect responses (either circumlocutions or semantic word substitutions) that he explicitly rejected as wrong, but did not try to correct. Incorrect responses bearing a close phonological or orthographic resemblance to the stimulus (e.g., reading *gabbia*, cage → /'kabbya/, instead of /'gabbya/; or, writing *fungo*, mushroom →

funco) were scored as "phonemic/graphemic" errors. The remaining errors (fragments, neologisms, unrelated word substitutions) were scored as "others". Note that comprehension tasks did not allow "phonemic/graphemic" errors, but only semantic and "other" errors.

In order to measure auditory and visual word comprehension, this time E.C.A. was asked to decide whether or not a word presented aurally or visually was the name of a picture. Three types of word–picture pairs were shown: a picture could be paired with the correct word, with a semantically-related word, or with an unrelated word. Both tests were administered in three sessions. Each picture ($N = 314$ per test) was presented once in each of the three sessions, for a total of 942 trials in each test. Since the goal of these tasks was to ascertain whether E.C.A. could semantically process the presented stimuli, the three presentations of each stimulus were scored as if they were a single item. Consequently, a test item was scored as having been correctly comprehended if the patient both correctly accepted the matching word–picture pair and appropriately rejected the two nonmatching word–picture pairs; conversely, it was scored as having been incorrectly comprehended if an incorrect response was produced to one or more of the word–picture pairs. E.C.A. produced correct responses to 247/314 (78.7%) auditory stimuli, and to 264/314 (84.1%) visual stimuli. All his errors in the two tasks consisted of either incorrectly accepting a semantic associate as correct, or incorrectly rejecting the correct name as the label for the picture; E.C.A. never accepted an unrelated word as the correct name for the presented picture, and never produced more than one incorrect response to the same item.

In evaluating the results obtained by E.C.A. in the oral and the written production tasks reported in this section it must be remembered that the stimuli used in these tasks were shorter than those used in the tasks reported in the previous section. Thus, a greater level of accuracy on some tasks in this section is not unexpected.

The analysis of Table 5 reveals important similarities as well as differences among tasks. In all tasks that require spoken or written output, phonemic/graphemic errors account for a similar number of incorrect responses (8% in reading aloud, 9.5% in repetition, 10.5% in writing to dictation, 11.5% in oral naming, 9.5% in written naming, and 9.2% in tactile naming). By contrast, striking differences are apparent in the rates of semantically-related responses. These errors occurred with comparable frequency in repetition (11.2%), writing to dictation (8.5%), oral naming (14%), written naming (12.7%), and tactile naming (11.1%). However, E.C.A. did not produce any semantic errors in the oral reading task, but he did produce 2 (0.6%) stress errors (scored as "other" errors), and 2 phonemically/visually incorrect responses that also contained a stress error (e.g. *ananas*, pineapple → /a'nanis/, instead of /'ananas/). Since most of the stimuli used in the present task were bisyllabic words (that are usually unambiguous with respect to stress assignment), fewer stress errors were observed in this sample than in the set of words reported earlier (0.6% vs 1.3%). However, if only stimuli that allow stress errors are considered, this type of incorrect response occurred in 2/94 (2.1%) cases.

In order to establish whether the observed commonalities in E.C.A.'s lexical processing impairments arise from damage to a common component of processing (the lexical semantic component) or from damage to various independent components of processing (the phonological and orthographic lexicons) we tested the null hypothesis of complete item inconsistency across tasks. Since semantic errors did not occur in reading, and since only a subset of stimuli was used for tactile naming, only performance in auditory and written word–picture verification, writing to dictation, repetition, oral and written naming was considered. Item consistency was measured with respect to three dimensions: overall number of errors; "semantic-type" responses (that is, the sum total of semantic substitutions, circumlocutions and omissions), and semantic substitutions. Note that what is being tested here does not concern claims about whether the damage involves an access or a storage deficit (see Ref. [31] for a discussion of this issue). The only reason for considering item consistency is to evaluate whether the same factors affect performance in different lexical processing tasks.

The expected incidence of a given number of incorrect responses (out of six tasks) to the same item in the case of no task interdependence was evaluated by the formula presented in HILLIS *et al.* [19],* and then compared by means of chi-square analyses with the observed incidence of incorrect responses. The results are reported in Table 6.

Table 6. Incidence of a given number of expected and observed incorrect responses to the same item

	1. Overall errors		2. Semantic-type errors		3. Semantic substitutions	
	Expected	Observed	Expected	Observed	Expected	Observed
0/6	73	115	127	162	154	178
1/6	121	85	125	82	119	86
2/6	83	53	50	40	35	32
3/6	30	38	11	22	5	14
4/6	6	13	1	5	1	4
5/6	1	10	0	3	0	0
6/6	0	0	0	0	0	0
	$\chi^2=35.316$ $P<0.001$		$\chi^2=23.614$ $P<0.001$		$\chi^2=13.244$ $P<0.05$	

Independently of the parameter entered in the comparison, the results always reached statistical significance (overall errors: $\chi^2=35.316$; $P<0.001$; semantic-type errors: $\chi^2=23.614$; $P<0.001$; semantic substitutions: $\chi^2=13.244$; $P<0.05$). These results show that the observed distribution of errors is significantly different from that expected in the case of no task interdependence. Thus, they are consistent with the shared-component deficit hypothesis (although they do not represent strong evidence against the multiple-component deficit hypothesis; see Ref. [26] for discussion of why the reported outcome does not represent strong evidence against the multiple-deficit hypothesis; see also Ref. [9], for a discussion of the limitations of such analyses, in general).

In short, as expected on the hypothesis of a common basis for the semantic errors produced by the patient in all lexical processing tasks (except for reading), the performance

*Expected values in the case of non-interdependence across tasks were calculated by summing all permutations that would end up in semantic errors on a given number of tasks. For example, in the case of non-interdependence across the six tasks considered for this analysis (auditory word–picture matching; visual word–picture matching; repetition; writing to dictation; oral picture naming; written picture naming), the expected incidence of semantic errors on two tasks was calculated by means of the following formula:

$$(P1 \times P2 \times Q3 \times Q4 \times Q5 \times Q6) + (P1 \times Q2 \times P3 \times Q4 \times Q5 \times Q6) + (P1 \times Q2 \times Q3 \times P4 \times Q6 \times Q6) + (P1 \times Q2 \times Q3 \times Q4 \times P5 \times Q6) + (P1 \times Q2 \times Q3 \times Q4 \times Q5 \times P6) + (Q1 \times P2 \times P3 \times Q4 \times Q5 \times Q6) + (Q1 \times P2 \times Q3 \times P4 \times Q5 \times Q6) \ldots \times 314.$$

In this formula, P1, P2, P3, etc. correspond to the probability that a semantic error occurs in tasks 1, 2, 3, etc., respectively; and Q1, Q2, Q3, etc. correspond to the probability that a semantic error does not occur in tasks 1, 2, 3, etc., respectively.

profiles across tasks we have reported for E.C.A. indicate strong commonalities both quantitatively and qualitatively.

DISCUSSION

The main features of E.C.A.'s performance can be easily summarized: (1) he is impaired in all lexical production (oral and written naming, oral reading, writing to dictation, and repetition) and comprehension tasks (auditory and visual word/picture matching tasks); however, (2) he produced different patterns of errors across different tasks: He produced semantic errors in all lexical processing tasks *but* oral reading, and he produced stress errors *only* in oral reading; (3) he is severely impaired in writing and repeating pseudowords but only mildly impaired in reading pseudowords; and (4) there are indications from error consistency analyses that his performance across tasks (excluding reading) may result, at least in part, from a common underlying deficit.

This patterm of performance has interesting implications for models of lexical processing. Of special interest here is the fact that E.C.A. produced semantic errors in all lexical processing tasks except in oral reading. As pointed out in the Introduction and in the Interim Discussion, the latter fact is an expected pattern of performance in a model of lexical processing such as the one schematically depicted in Fig. 1. In particular, the selective absence of semantic errors in some task(s) in the context of indications of a lexical–semantic deficit supports the Summation Hypothesis in models of reading and writing proposed by HILLIS and CARAMAZZA [17, 18]. That is, the pattern of results supports the hypothesis that the activation of phonological or orthographic lexical forms can be constrained by sublexical phonological or orthographic information, as the case might be.

The Summation Hypothesis assumes that information activated by a semantic representation in the output lexicon(s) summates with information assembled by sublexical conversion mechanisms during production, effectively blocking the production of semantically-related responses in the case where a semantic deficit might have led to the activation of an incorrect lexical form. Thus, the Summation Hypothesis predicts that semantic errors in lexical processing tasks are possible only if damage affects *both* the semantic–lexical component, *and* one or more of the sublexical procedures that convert phonology into orthography into phonology. In the case of E.C.A., co-occurring damage to the semantic subcomponent and to sublexical mechanisms for mapping sound to print results in semantic errors in writing to dictation: semantically-related orthographic representations activated by impoverished semantic information cannot be prevented from reaching threshold by information computed by print-to-sound mapping procedures. In a similar fashion, the co-occurrence of damage to the semantic component and to those mechanisms that convert a sublexical phonological input string into a phonological output string results in semantic errors in repetition. By contrast, semantic errors are not produced in reading aloud by E.C.A. because even though he has damage to the semantic component his relatively spared ability to convert print to sound nonlexically effectively blocks the production of such errors. In other words, in reading, the semantically-incorrect representations activated by degraded semantic information in the phonological output lexicon are effectively prevented from reaching threshold by the phonological information assembled by sublexical print-to-sound mapping procedures. This hypothesis also accounts for the presence of semantic errors in naming objects presented visually or tactilely. Unlike the relation between phonological and orthographic lexical forms, the relation between the shape of an object and the corresponding phonological or orthographic lexical form is entirely arbitrary. As a consequence, the only information that can be used to constrain lexical production in object naming tasks is the lexical–semantic information computed from the stimulus objects, leading to the production of semantic errors in the case of damage to the semantic component.

Our account of E.C.A.'s performance can now be phrased more explicitly. E.C.A. fails to produce semantic errors in reading because, even though the semantic component of the lexical system is damaged, spared sublexical orthography to phonology conversion blocks the suprathreshold activation of semantically related responses. He makes semantic errors in writing to dictation and in repetition because severe impairment of the sublexical conversion mechanisms involved in these tasks (phonology to orthography, and input phonology/output phonology, respectively), co-occurring with semantic damage, minimizes their contribution to the activation of lexical form with the appropriate phonological or orthographic characteristics, as the case may be. Finally, semantic errors in word–picture verification and in picture naming result from semantic damage (since in these tasks there is no interaction between sublexical and semantic mechanisms, impairment of the semantic subcomponent alone accounts for the occurrence of semantically incorrect responses). In short, E.C.A.'s performance can be given a clear explanation in the framework of a model of lexical processing that assumes summation of activation in the phonological and orthographic output lexicons [17], lending further support to the latter hypothesis of the organization of lexical processes. Finally, we should note that although MARSHALL and NEWCOMBE'S [23] explanation of the cause of semantic paralexias can also account for E.C.A.'s pattern of performance, as noted in the Introduction, we prefer the Summation Hypothesis since it provides a better fit for performance in cognitively unimpaired subjects.

The Summation Hypothesis also provides a reasonable account for a well-known phenomenon that has received only scant attention in the literature: an asymmetry in the occurrence of semantic paralexias and paragraphias between languages with transparent vs opaque orthographies [1]. If the number of published papers on a given topic can be taken as a rough index of the incidence of various patterns of cognitive impairment, two conflicting sets of results concerning the production of semantic errors are observed across different languages. In tasks such as word–picture matching or picture naming, where no interaction between lexical and sublexical mechanisms is hypothesized, speakers of opaque and of transparent languages appear to be equally likely to produce semantically related incorrect responses. Thus, for example, the production of semantic errors in naming and word–picture matching is regularly observed in Italian- [13, 14] and Spanish-speaking (e.g. Refs [2] and [3]) aphasics. By contrast, a striking discrepancy between opaque and transparent languages is observed in the occurrence of semantic paralexias and paragraphies. In the case of reading aloud and of writing to dictation (we will consider repetition later), almost all the patients who produce semantic paralexias (e.g. the cases in Ref. [10]) and paragraphias (e.g. Refs [5, 7, 19, 20, 22, 30] are speakers of opaque languages. To our knowledge, there are only two reports of Italian-speaking [21, 28] and three of Spanish-speaking [12, 32] patients who produce semantic paraphasias in oral reading. Aside from our case E.C.A., there are no reports of Italian or Spanish speaking patients who produce semantic paragraphias. Why is this the case? Why the asymmetry in the occurrence of semantic errors in reading and writing in speakers of languages with transparent vs opaque orthographies? The two sets of tasks in which aphasic speakers of opaque and transparent languages show contrasting performance differ in one crucial respect from the perspective of the Summation Hypothesis: word–picture matching and picture naming do not involve an interaction between lexical and sublexical processing mechanisms, whereas such an interaction is hypothesized to take place in oral reading and in writing to dictation. Thus, the role of the interaction between lexical and sublexical processing mechanisms is the obvious candidate for an interpretation of the observed discrepancy.

The explanation we would like to propose is the following. In opaque languages, sublexical conversion involved in reading aloud and in writing to dictation requires complex, sophisticated mappings (mostly many-to-one or one-to-many; see Refs [4], [16] and [35]). By contrast, in transparent languages sublexical conversion is very "simple", and consists almost entirely of one-to-one mappings. As a consequence, the same cognitive damage to sublexical conversion mechanisms in a language with transparent and in one with opaque orthography might result in vastly different consequences in reading and writing performance: In opaque languages, it could lead to a severe functional deficit of sublexical conversion; whereas in transparent languages it would interfere only minimally with sublexical conversion. Thus, in a language with opaque orthography, damage to a sublexical conversion procedure would result in a situation where the output of the damaged component would consist of relatively unusable information in constraining the activation of lexical entries in the relevant output lexicon. By contrast, in a language with transparent orthography the comparable amount of damage to a sublexical conversion procedure would have relatively minor effects on the information value of the output of the damaged process, at least with respect to its role in constraining the activation of lexical forms in the relevant output lexicon. The obvious consequence of these contrasting situations is that transparent orthography languages are relatively "protected" from the production of semantic paralexias and paragraphias because the sublexical conversion mechanisms even when damaged continue to provide information that is useful in constraining the activation of phonological and orthographic lexical forms.

The hypothesis that the complexity of sublexical conversion systems is related to the probability of occurrence of semantic errors is also substantiated by the discrepancy observed in opaque languages between the occurrence of semantic errors in reading aloud and writing to dictation as opposed to repetition. Thus, for example, the number of aphasic English speakers who produce semantic errors in reading aloud and in writing to dictation is fairly high. By contrast, far fewer subjects produce the same errors in repetition (for a review, see Refs [20] and [22]). In repetition, even in orthographically opaque languages, input–output conversion is based on one-to-one mappings (/p/ in an input string always corresponds to /p/ in the output string!). Thus, this sublexical conversion is much simpler than the conversion needed for reading aloud and writing to dictation (and is of comparable complexity in all languages, opaque and transparent). As a consequence, in opaque languages fewer patients produce semantic errors in repetition than in reading aloud and in writing to dictation.

To conclude, the data from patient E.C.A. provide support for the Summation Hypothesis in reading and writing. They also show that, in the framework of this hypothesis, given the proper cognitive damage, speakers of transparent languages make semantically related incorrect responses, just like their opaque-language speaking counterparts. Furthermore, the Summation Hypothesis offers a framework within which to account for the differential occurrence of semantic errors in transcoding tasks among speakers of opaque and of transparent languages, and for the lower incidence of semantic errors in repetition as opposed to reading aloud and writing to dictation in opaque languages.

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