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Deficits on irregular verbal morphology in Italian-speaking Alzheimer's disease patients

Matthew Walenski[a,d,*], Katiuscia Sosta[b], Stefano Cappa[c], Michael T. Ullman[a,**]

[a] Brain and Language Laboratory, Departments of Neuroscience, Linguistics, Psychology and Neurology, Georgetown University, United States
[b] IRCCS S. Giovanni di Dio-FBF, Brescia, Italy
[c] Centro di Neuroscienze Cognitive, Universita Vita-Salute S. Raffaele, Milano, Italy
[d] Department of Psychology, University of California, San Diego, United States

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ABSTRACT

Studies of English have shown that temporal-lobe patients, including those with Alzheimer's disease, are spared at processing real and novel regular inflected forms (e.g., *walk* → *walked*; *blick* → *blicked*), but impaired at real and novel irregular forms (e.g., *dig* → *dug*; *spling* → *splang*). Here we extend the investigation cross-linguistically to the more complex system of Italian verbal morphology, allowing us to probe the generality of the previous findings in English, as well as to test different explanatory accounts of inflectional morphology. We examined the production of real and novel regular and irregular past-participle and present-tense forms by native Italian-speaking healthy control subjects and patients with probable Alzheimer's disease. Compared to the controls, the patients were impaired at inflecting real irregular verbs but not real regular verbs both for past-participle and present-tense forms, but were not impaired at real regular verbs either for past-participle or present-tense forms. For novel past participles, the patients exhibited this same pattern of impaired production of class II (irregular) forms but spared class I (regular) production. In the present-tense, patients were impaired at the production of class II forms (which are *regular* in the present-tense), but spared at production of class I (regular) forms. Contrary to the pattern observed in English, the errors made by the patients on irregulars did not reveal a predominance of regularization errors (e.g., *dig* → *digged*). The findings thus partly replicate prior findings from English, but also reveal new patterns from a language with a more complex morphological system that includes verb classes (which are not possible to test in English). The demonstration of an irregular deficit following temporal-lobe damage in a language other than English reveals the cross-linguistic generality of the basic effect, while also elucidating important language-specific differences in the neurocognitive basis of regular and irregular morphological forms.

1. Introduction

Language depends on both idiosyncratic mappings and mappings that can be described by rules. Idiosyncratic mappings include all arbitrary sound-meaning associations (e.g., /kæt/ refers to the small furry feline) and word-specific morphological information (e.g., *spring* takes *sprang* as its irregular past-tense form). Mappings that can be described by rules include the combination of words and parts of words into complex words (e.g., in regular past-tenses, such as *walk* + *-ed*), phrases and sentences.

One intensively studied approach to examining the computational and neurocognitive distinction between these aspects of language has been to investigate the contrast between irregular and regular morphology, in particular in English past-tense formation (Clahsen, 1999; Joanisse & Seidenberg, 1999; Pinker, 1999; Pinker & Ullman, 2002b; Rumelhart & McClelland, 1986; Ullman, 2001b; Ullman et al., 1997). Whereas irregular past-tense formation is at least partly idiosyncratic (*bring* → *brought*, *sing* → *sang*), and so must depend at least in part on memorized representations, regular past-tense formation can be described by a simple default rule (*-ed*-affixation).

The regular/irregular English past-tense distinction has been examined using many methodological approaches. Here we focus on data directly relevant to the present study, namely data from testing patients with neocortical temporal-lobe damage, but relatively spared frontal/basal-ganglia circuits. These studies have

* Corresponding author at: Department of Psychology, University of California, San Diego, 9500 Gilman Drive, Mail Code 0109, La Jolla, CA 92093-0109, United States.
** Corresponding author at: Department of Neuroscience, Georgetown University, 3970 Reservoir Road, NW, Box 571464, Washington, D.C. 20057-1464, United States. Tel.: +1 202 687 6064; fax: +1 202 687 6914.
E-mail addresses: mwalenski@ucsd.edu (M. Walenski), michael@georgetown.edu (M.T. Ullman).

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revealed deficits in the production of real and novel irregular past-tenses (e.g., *dig* → *dug*, *spling* → *splang*), while real and novel regular past-tense production remains relatively spared, even when dementia scores or other measures of general cognitive impairment are factored out. This pattern has been reported for posterior aphasics and other patients with adult-onset temporal-lobe damage following stroke (Miozzo, 2003; Ullman et al., 1997; Ullman et al., 2005), patients with probable Alzheimer's disease (Cortese, Balota, Sergent-Marshall, Buckner, & Gold, 2006; Ullman, in press; Ullman et al., 1997), semantic dementia patients (Cortese et al., 2006; Patterson, Lambon Ralph, Hodges, & McClelland, 2001; but see Tyler, 2004), and individuals with herpes simplex encephalitis (Tyler et al., 2002). A similar pattern has been found in reading and judgment tasks in posterior aphasia (Ullman et al., 2005), and in a priming task in both a patient with adult-onset temporal-lobe damage, and a patient with semantic dementia (Marslen-Wilson & Tyler, 1998, 1997). This dissociation between regular and irregular inflected forms, for both real and novel verbs, has been explained in different ways by different neurocognitive models of language.

"Dual-system" models of language assume that the distinction between irregular and regular English past-tense forms depends on a fundamental distinction between the "mental lexicon" and the "mental grammar" (Clahsen, 1999; Marslen-Wilson & Tyler, 1998; Pinker, 1999; Pinker & Ullman, 2002b; Ullman, 2001a). The mental lexicon is a repository of stored information, including all idiosyncratic word-specific information, such as what irregular (unpredictable) morphological forms a word may take (e.g., *dig* takes *dug* as its past-tense form). On this view, the mental lexicon depends on an associative memory system (i.e., not simply a rote memory store) that can generalize patterns from already-stored forms to new ones (e.g., from *sing* → *sang*, *spring* → *sprang* to the novel irregular *spling* → *splang*) (Pinker & Ullman, 2002a; Rumelhart & McClelland, 1986). The mental grammar underlies the rule-governed combination of lexical forms into complex linguistic representations (e.g., the combination of *man*, *bite*, *-s*, and *dog*), in phrases, sentences, and complex words such as *walked*. Thus real and novel regular past-tenses (e.g., *walked*, *blicked*) are posited to be generally computed by the mental grammar, which combines word bases (e.g., *walk*) with affixes (e.g., *-ed*). This grammatical combination is a default process, and applies to any form for which the associative memory system cannot produce an acceptable output by either retrieving a memorized form (e.g., *sang*) or generalizing to a novel form (e.g., *splang*); in contrast, successful output from the associative memory system should "block" application of the rule (Marcus et al., 1992; Pinker, 1999; Pinker & Ullman, 2002b).

According to one dual-system model, the Declarative/Procedural (DP) model, the mental lexicon and the mental grammar depend on specific distinct brain systems (Ullman, 2001a, 2001b, 2004; Ullman et al., 1997; Ullman et al., 2005). This model posits that the mental lexicon relies on the declarative memory system, which subserves the learning and use of knowledge about facts and events. This system is rooted largely in temporal-lobe structures: The hippocampus and other medial temporal structures consolidate and retrieve new memories, which eventually come to depend largely on neocortical regions, particularly in the temporal lobes (Eichenbaum & Cohen, 2001; Hodges & Patterson, 1997; Martin, Ungerleider, & Haxby, 2000; Squire, Stark, & Clark, 2004). Aspects of the mental grammar instead depend on procedural memory, which underlies the acquisition and expression of motor and cognitive skills and rules, and is rooted largely in frontal/basal-ganglia structures. Therefore, the DP model predicts a dissociation between regular and irregular morphological forms in patients with neocortical temporal-lobe damage, who should show a relative deficit on real and novel irregulars (*sang*, *splang*), with relative sparing of real and novel regulars (*walked*, *blicked*).

"Single-mechanism" models argue against a neurocognitive dissociation between lexicon and grammar, and instead posit that the learning and use of both the words and (descriptive) rules of language depend on a single computational mechanism (Bates & MacWhinney, 1989; Elman et al., 1996; MacDonald, Pearlmutter, & Seidenberg, 1994; McClelland & Patterson, 2002; Seidenberg, 1997). Connectionist theory offers a computational framework for the single-mechanism view, whereby the learning, representation, and processing of all language mappings take place over a large number of inter-connected simple processing units (Elman et al., 1996; Rumelhart & McClelland, 1986; Seidenberg, 1997).

One single-mechanism account characterizes neurocognitive dissociations between regular and irregular English past-tense forms in terms of dissociations between phonology and semantics (Joanisse & Seidenberg, 1999; McClelland & Patterson, 2002; Patterson et al., 2001). On this view, in which posterior cortical regions subserve semantic processing, while anterior cortical regions subserve phonological processing, the production of irregular past-tenses is hypothesized to depend more on semantics relative to phonology than is the production of regulars or novels, which are posited instead to show a greater relative reliance on phonology. Thus temporal-lobe damage leading to semantic deficits is predicted to impair irregulars, leaving regular and novel past-tense production relatively spared. Indeed, in a connectionist simulation of semantic damage to a model with distinct nodes for semantics and phonology, lesioning the model's semantic representations led to worse performance at producing past-tenses of irregulars than of real regulars and novel regulars (e.g., *blick* → *blicked*) (Joanisse & Seidenberg, 1999). Thus temporal-lobe damage leading to semantic deficits in patients is expected to impair real irregulars (*sang*), but leave both real regulars and novel regulars (*blicked*) relatively spared. The case of novel irregulars (e.g., *spling* → *splang*) has not been addressed by this model. However, since it is suggested that all novel forms depend on phonology, with no claims of a greater dependence on semantics for novel irregulars than novel regulars (Joanisse & Seidenberg, 1999; McClelland & Patterson, 2002), no relative deficit of novel irregulars as compared to novel regulars would be expected.

In order to demonstrate the cross-linguistic generality of the pattern found in English, which has an atypically impoverished morphological system, it is necessary to show the same pattern in other languages, particularly those with more complex morphological systems such as Italian. The examination of temporal-lobe patients in such a language provides the opportunity to test the generality of the pattern observed in English, whereas any language-specific differences may enable further specification of the underlying neurocognitive mechanisms.

1.1. Italian verbal morphology

Here we focus on Italian past-participle and present-tense inflection. Both of these inflections contain a large number of irregular verbs (Vincent, 1987), allowing regular and irregular forms to be contrasted. Irregular verbs are defined here as those which undergo stem-changes from the infinitival stem to the stem of the inflected form (e.g., ***ven**-ire* → ***vien**-i*). Regular verbs, by contrast, are defined as those that undergo no such stem-changes (e.g., ***am**-are* → ***am**-i*).

Unlike English, Italian verbs are traditionally divided into three morphological classes. These are distinguished by the thematic vowel – *-a-* (class I), *-e-* (class II), and *-i-* (class III) – in the infinitival form of the verb, as in *am**a**re* 'love', *tem**e**re* 'fear', and *ven**i**re* 'come' (Napoli & Vogel, 1990). Class I is by far the largest class (containing the most verbs) as well as the most regular class, with almost no irregular members (Napoli & Vogel, 1990). It is also the default class, used for new verbs entering the language (e.g., *chattare* 'to chat on the internet'). In contrast, roughly 95% of class II verbs display some morphological irregularity (Say & Clahsen, 2002). While class III has few irregular members, the morphological patterns of class III verbs are more similar to those of class II than class I verbs, and it has been proposed that Italian really has only two classes: one for verbs with infinitives in *–are* (essentially a regular class), and one for verbs with infinitives in *–ere* or *–ire* (essentially an irregular class) (Napoli & Vogel, 1990; Say & Clahsen, 2002; Vincent, 1987).

To create the regular past-participle (e.g., *amato* for class I verbs), the verb root (*am-*) is combined with the thematic vowel (*-a-* for class I), the affix *–t-*, and a gender/number agreement affix (e.g., masculine singular *–o*). Most class I and class III verbs are regular in the past-participle (e.g., *andare* → *andato* 'go', *salire* → *salito* 'climb'), whereas most class II verbs have irregular (stem-changing) past-participles (e.g., *discútere* → *discusso* 'discuss').

Regular present-tenses are formed by adding one of six person/number agreement affixes to the infinitival stem (e.g., *am*-o 'I love' from *amare*). Irregular present-tenses are created by adding the agreement affix to a stem other than the infinitival stem (e.g., *potere* → *posso* 'be able'; *uscire- èsco* 'go out'). Some irregular class II verbs change their stems only by adding a *-g-* augment before a person/number affix (e.g., *valere* → *val-g-o* 'win'). This augment is added in an entirely predictable manner, to all verbs whose infinitival stems end in the phonemes /l/, /ʎ/, /n/, or /ɲ/ (spelled *–l-*, *-gl-*, *-n-*, and *-gn-*, respectively). However, it is still unclear whether the *-g-* augment for class II verbs is added productively or is memorized as part of an irregular stem. Class III verbs may also add an augment (either the -g- augment or an -isc- augment), though these augments must involve some kind of memorized representation, since it is not predictable whether a given class III verb will take an augment (Vogel, 1993).

A previously proposed dual-system model of Italian past-participle morphology (Say & Clahsen, 2002) argues that class I regular past-participles (e.g., *amato*) rely on a default rule that adds the thematic vowel *-a-* to the verb's root to form the past-participle stem (e.g., *am-* + *–a-* yields *ama-* 'love'), and another that adds the default affix *–to*. In contrast, *all* class II and class III verbs are posited to depend on memory. Those with stem-changes are simply memorized as whole forms (e.g., *préso* from *prèndere* 'take'), while those that are regular within class II or III have memorized past-participle stems (e.g., *sali-* for *salire* 'climb'), to which the default rule adds the past-participle affix *–to* (*salito*). On this view the regular/irregular dissociation is clearest between the fully default class I regular forms (e.g., *amato*), and fully irregular forms (*préso*) from class II, and to a lesser extent from class III. It is this distinction that we focus on here.

1.2. The current study

We examined past-participle and present-tense production of real regular (*creare* → *creato* '*create*'; *arrivare* → *arrivo* '*arrive*') and real irregular (*rìdere* → *riso* '*laugh*'; *uscire* → *èsco* '*go out*') as well as novel class I (*carlàre*) and class II (*nìggere*) verbs both in a group of patients in the early stages of probable Alzheimer's disease (pAD) and in elderly healthy control subjects. Patients with pAD constitute a highly appropriate group to examine the regular/irregular contrast, as in its early stages the neuropathology of AD heavily affects not only medial temporal structures, but extends to neocortical temporal-lobe structures, while leaving basal ganglia and frontal areas relatively spared (Arnold, Hyman, Flory, Damasio, & Hoesen, 1991; Kemper, 1994). Moreover, pAD patients have previously shown clear deficits on English irregulars (see above), with relative sparing of real and novel regulars and other aspects of grammar (Nebes, 1997; Ullman, 2001a, 2004).

The dual-system Declarative/Procedural model predicts a deficit in pAD patients as compared to controls, in both past-participle and present-tense production, of real irregular inflected forms, with a relative sparing of real regular forms. The model also predicts that for novel verbs the pAD patients should be impaired at irregularized but not regularized inflected forms. Moreover, following the pattern observed in English (e.g., Alzheimer's patients often utter *digged* instead of *dug*) (Cortese et al., 2006; Ullman et al., 1997), errors on irregular verbs may frequently take the form of regularized responses.

Similarly, the single-mechanism model discussed above (Joanisse & Seidenberg, 1999; McClelland & Patterson, 2002) also predicts a greater deficit at real irregular than real regular inflected forms, for both past-participle and present-tense production. However, the model predicts a relative sparing of all novel inflected forms, with no difference in accuracy between class I and class II novel verbs, for either past-particle or present-tense production. Errors, particularly on real irregulars, should be consistent with semantic damage, and thus might often take the form of semantic substitutions.

2. Methods

2.1. Subjects

Twenty-four right-handed native Italian speakers participated in this study: 12 patients diagnosed with probable Alzheimer's disease and 12 elderly healthy control subjects (Table 1). In addition, a third group of young control subjects participated only in a pretest of our materials, and were not compared with either the patients or the elderly controls.

2.2. Design and materials

All subjects were tested on both a past-participle and a present-tense elicitation task (Tables 2 and 3). Each task consisted of four types of verbs: real regulars (class I regular verbs, with no stem changes; e.g., *domandare* → *domandato, provare* → *provo*), real irregulars (class II or III irregular verbs, with stem changes; e.g., *giùngere* → *giunto, tenere* → *tèngo*), novel class I verbs (e.g., *delare* → *delato, carlare* → *carlo*), and novel class II verbs (e.g., *schidere* → *schiso, contrimere* → *contrimo*). For details of the criteria regarding the selection of real verbs and the construction of novel verbs, see the notes to Tables 2 and 3. For each task, the verb-types were intermixed and pseudo-randomly ordered, such that no more than three verbs of any verb type were presented consecutively.

In the past-participle task, all verbs were presented in sentences with the following structure ("/" indicates a line break): *A Giovanni piace ballare il tango. / Allora ieri Giovanni ha ___ il tango*. (John likes to dance the tango. / So yesterday, John has ___ the tango.) A third-person singular masculine subject was used in all past-participle sentences. In the present-tense task, all verbs were presented in sentences with the structure "*Mi piace andare in montagna. / Allora ogni giorno ___ in montagna*. (I like to go to the mountains. / So every day (I) ___ to the mountains.)". The pronoun *Mi* was used in all present-tense sentences. The post-verbal phrases differed for every verb in each task. Each two-sentence context was typed on a single sheet of paper for presentation to subjects.

2.3. Procedure

Following Ullman et al. (1997), subjects were asked to read the sentences out loud and orally fill in the blank with the appropriate form of the verb. Subjects were re-prompted if they misread the verb, hesitated, or failed to respond. If subjects couldn't read the sentences, the experimenter read them out loud. Because the same novel verbs were presented in both tasks, the order of presentation of the past-participle and present-tense tasks was counterbalanced across subjects within each group. Within each task, items were presented in the same order for all subjects. Four practice verbs (one real regular, one real irregular, one novel class I, one novel class II) were included at the beginning of each task.

2.4. Pretest

We pretested the novel items on 50 young (14 men, 36 women; mean age: 30.1 years) college-educated (mean years of education: 16.6, all had university degrees) cognitively unimpaired subjects, to test whether the novel class I verbs would be regularized, and whether the novel class II verbs would be irregularized (see Response Coding below for definitions of regularizations and irregularizations). In the past-participle sentence contexts the novel class I verbs were uniformly regularized, and the novel class II verbs yielded primarily irregularized responses (85.9%), with a small number (11.5%) of regularized responses (i.e., the stem affixed with the class I affix *–ato*). In the present-tense contexts, all of the novel class I and class II verbs were regularized (100%). This was not surprising, given the lack of phonological sim-

Table 1
Subject information.

pADs	BL	BA	CAM	COM	CT	MC	ML	MA	ZT	ZL	FE	GA	pAD mean (S.D.)	Control mean (S.D.)
n													12	12
Age (years)	76	72	75	73	90	79	85	82	83	70	65	70	76.7 (7.3)	73.4 (5.5)
Education (years)	10	5	5	8	8	8	5	17	11	5	5	5	7.7 (3.7)	7.9 (2.6)
MMSE	19	22.3	17.7	25.4	21.8	19	22.4	21.1	22.7	20.3	24.9	24.3	21.7 (2.4)	28.2 (1.5)
Boston Naming	27	9	13	15	15	9	17	25	24	17	15	25	17.6 (6.2)	26.4 (1.4)
CDR	1	1	1	1	1	1	1	1	1	1	1	1	1	–
Handedness	R	R	R	R	R	R	R	R	R	R	R	R	12 R	12 R
Sex	M	F	F	F	F	F	F	F	F	F	F	F	1 M/11 F	2 M/10 F

Patients were enrolled in the Alzheimer Disease Unit of the Sacro Cuore Fatebenefratelli Hospital, in Brescia, Italy. All patients met National Institute of Neurological and Communications Disorders and Stroke, and Alzheimer's Disease and Related Disorders Association (NINCDS-ADRDA) criteria for probable AD (McKhann, Drachman, Folstein, Katzman, & Price, 1984), and were mildly impaired according to clinical evaluations and scores on the mini-mental state exam (MMSE) (Folstein, Folstein, & McHugh, 1975) and the Clinical Dementia Rating scale (CDR) (Berg, 1988). MMSE scores reported here are corrected for age and education. The 12 cognitively unimpaired control subjects did not differ from the pAD patients in either age ($t(22) = 1.24$, $p = 0.23$) or years of education ($t(22) < 1$). The MMSE scores were (as expected) significantly lower for the pADs than controls ($t(22) = 7.82$, $p < 0.0001$). Likewise, Boston Naming scores (Goodglass, Kaplan, & Weintraub, 1983) were lower for the patients than the controls ($t(22) = 4.79$, $p = 0.0001$), consistent with lexical deficits among the pADs. The control subjects were not tested on the CDR. Subjects (patient or control) with potentially confounding neurological or psychiatric disorders, alcohol or drug abuse, hearing or vision impairment, severe metabolic disturbance, or head injury were not included in this study.

ilarity between the novel class II verbs and real verbs with irregular present-tense forms (see Table 3).

2.5. Response coding

An item was coded as correct if it elicited at least one correct (for real verbs) or expected (for novel verbs) response. This liberal scoring criteria works against any prediction of a deficit, since patients have more opportunities to provide correct responses. For novel past-participles, the expected response to class I verbs was the regularized form (infinitival stem + *-ato*). The expected response to novel class II verbs was an irregularization, defined as stem-past-participle transformations similar to those of existing irregular past-participles. Thus both *decusso* and *decuso* were considered irregularizations of the novel class II verb *decùtere*, given their similarity to the existing transformations *discùtere* → *discusso* ('*discuss*') and *divìdere* → *diviso* ('*divide*'). Responses to novel class II verbs formed with infinitival stem + *-uto* (which are traditionally seen as regular within their morphological class) were counted as irregularizations, because evidence suggests that their stems – e.g., *temu-* of *temere* 'fear' – may be memorized (Say, 1999). The rates of such responses were low (pAD: 3.1%; controls: 4.7%), and the results did not change when such forms were instead counted as regularization errors (i.e., together with *–ato*-affixed forms). For the novel present-tense verbs, the expected response for class I *and* class II verbs was defined as the regularized form (i.e., *-o*-suffixed infinitival stems; e.g., *carlare* → *carlo*), based on the results from the pretest (see above). Whenever the subject did not produce any correct or expected response, the first response was coded as an error.

Note that in Italian, the stems of novel class II infinitives with stem-final affricates (/tš/ or /dž/) are ambiguous – some real verbs with a stem-final affricate in the infinitive keep the affricate in their inflected forms (e.g., "to cook" *cuòcere* → *cuòcio*), whereas others exhibit a stem-final stop (/k/ or /g/) in the inflected form (e.g., "to win" *vìncere* → *vinco*). Therefore, responses to the eight novel class II verbs with a stem-final affricate in the infinitive (*dorcere, ammingere, stengere, stergere, ciolgere, niggere, nungere, norgere*) were scored as non-stem-changing (i.e., as regularizations) with either the stop or the affricate in the response (e.g., *dorcio, dorco* were both considered expected present-tense responses for *dorcere*).

2.6. Analysis

All analyses are presented with subjects (F_1, t_1) and items (F_2, t_2) as the error terms, with mean accuracy or error rates as the dependent variable. In the present-tense task, one real irregular verb – *udire* 'to hear' – was excluded from all analyses because 10 of the 12 control subjects responded with *sento*, the correct form of the synonymous and more commonly used *sentire* 'to hear'. For between-group and between-verb-type subject and item *t*-tests (both unpaired), degrees of freedom were estimated with the Satterthwaite approximation when unequal variance obtained between-groups (denoted with a subscript "s": t_{1s}, t_{2s}), as indicated by a significant Folded-*F* test. Interactions were examined with repeated-measures Analyses of Variance (ANOVAs). All *p*-values are presented 2-tailed.

To determine whether any results could be potentially confounded by group or verb-type differences on variables unrelated to our hypotheses, we followed up on those variables that differed ($p \leq 0.1$) either between subject groups or verb types. If any of these variables *also* correlated ($p \leq 0.1$) with accuracy for a given condition (real past-participle, real present-tense, novel past-participle, novel present-tense), they were included for that condition in an appropriate ANCOVA analysis, with follow-up between-group or verb-type *t*-tests on the adjusted means.

MMSE dementia scores reflect contributions from a variety of different underlying functions, including lexical memory. Since lexical memory is of particular interest in this study, it is important to exclude its contributions to MMSE scores when these scores are covaried out. We therefore calculated the residuals from the regression line of the Boston Naming scores (reflecting lexical processing) on the MMSE scores, and used these residuals (i.e., the portion of the MMSE scores not predicted by Boston Naming) rather than the original MMSE scores in the relevant ANCOVAs.

Of the potentially confounding subject-related factors that were examined, only one differed ($p \leq 0.1$) between subject groups (age- and education-adjusted MMSE scores), while four did not (age; education; handedness; sex); see Table 1. The MMSE dementia residuals correlated only with performance on real present-tense items (for irregulars: $r = 0.41$, $p = 0.04$). Of the potentially confounding item-related factors (lemma frequency, infinitival frequency, inflected-form frequency, orthographic length, phonological length, and a measure of phonological complexity; Tables 2 and 3), only the two length measures differed between verb types (between novel class I and II verbs, and between real regular and irregular present-tense verbs). These two length measures correlated only with performance at novel past-participle production (for control subjects: orthographic length, $r = -0.36$, $p = 0.05$; phonological length, $r = -0.36$, $p = 0.04$). In all and only these cases therefore, these factors (that both differed and predicted performance) were included as covariates in the appropriate ANCOVAs. Note that no factors both differed and predicted performance for the real past-participle or novel present-tense items.

3. Results

The patients showed a relative deficit on both real irregular (vs. regular) verbs and novel class II (vs. class I) verbs in both past-participle and present-tense production (Table 4).

3.1. Real past-participle

On real past-participles (Table 4A), the pAD patients performed significantly worse on irregulars than regulars (95.3% vs. 99.7%; $t_1(11) = 2.86$, $p = 0.02$; $t_{2s}(30.1) = 2.13$, $p = 0.04$). This deficit was not observed in the control subjects (irregular: 99.4%; regular: 100%; $t_1(11) = 1.48$, $p = 0.17$, $t_{2s}(29) = 1.00$, $p = 0.33$). Moreover, the pADs were significantly worse than control subjects on irregulars ($t_{1s}(12.5) = 2.79$, $p = 0.02$; $t_2(29) = 2.35$, $p = 0.03$), but not on regulars ($t_{1s}(11) = 1.00$, $p = 0.34$, $t_2(29) = 1.00$, $p = 0.33$). The interaction between subject group (pAD/control) and verb-type (regular/irregular) was significant (ANOVA: $F_1(1,22) = 6.53$, $p = 0.02$; $F_2(1,58) = 4.68$, $p = 0.04$). ANCOVA analyses were not performed, as no factors met the criteria for inclusion as covariates (see Section 2.6).

3.2. Real present-tense

The results for real present-tense production were similar to those for real past-participle production (Table 4B), although the items-analyses generally only approached significance, likely because of the small number of real present-tense items (half as many as real past-participle items; see Table 2). The pAD patients performed worse on irregulars than regulars (92.8%

Table 2
Real verbs and correct responses in the past-participle and present-tense tasks.

A. Past-participle		B. Present-tense	
Regular	Irregular	Regular	Irregular
affrontare → affrontato *confront*	accèndere → accéso *kindle*	aiutare → aiuto *help*	agire[a] → agisco
ascoltare → ascoltato *listen to*	appèndere → appéso *hang*	arrivare → arrivo *arrive*	andare → vado *go*
baciare → baciato *kiss*	aprire → apèrto *open*	cercare → cerco *seek*	bére → bévo *drink*
ballare → ballato *dance*	bére → bevuto *drink*	chiamare → chiamo *call*	cògliere[a] → còlgo *gather*
camminare → camminato *walk*	chièdere → chièsto *ask for*	cominciare → comincio *begin*	dire → dico *tell*
cenare → cenato *have supper*	chiùdere → chiuso *shut*	curare → curo *take care of*	finire[a] → finisco *end*
cercare → cercato *seek*	cògliere → còlto *gather*	donare → dono *donate*	rimanére[a] → rimango *remain*
collegare → collegato *join*	córrere → córso *travel*	girare → giro *turn*	salire[a] → salgo *climb*
comprare → comprato *buy*	difèndere → diféso *defend*	guardare → guardo *watch*	sapére → sò *know*
confermare → confermato *confirm*	dipèndere → dipéso *depend*	ingannare → inganno *deceive*	scégliere[a] → scélgo *choose*
consegnare → consegnato *deliver*	dirìgere → dirètto *direct*	negare → nego *deny*	sedére → sièdo *sit*
creare → creato *create*	discùtere → discusso *discuss*	pagare → pago *pay*	tenére[a] → tèngo *have*
cucinare → cucinato *cook*	distìnguere → distinto *distinguish*	parlare → parlo *speak*	trarre → traggo *pull*
dedicare → dedicato *dedicate*	divìdere → diviso *divide*	pensare → penso *think*	udire → òdo *hear*
domandare → domandato *ask*	erìgere → erètto *build*	studiare → studio *study*	uscire → èsco *go out*
girare → girato *turn*	giùngere → giunto *join*	trovare → trovo *find*	venire[a] → vèngo *come*
inventare → inventato *invent*	mòrdere → mòrso *bite*		
lavare → lavato *wash*	muòvere → mòsso *move*		
lavorare → lavorato *work*	nascóndere → nascósto *hide*		
mangiare → mangiato *eat*	offrire → offèrto *offer*		
mescolare → mescolato *mix*	pórre → pósto *put*		
parlare → parlato *speak*	prèndere → préso *take*		
portare → portato *carry*	protèggere → protètto *protect*		
saltare → saltato jump	rìdere → riso *laugh*		
scaricare → scaricato *unload*	rispóndere → rispósto *answer*		
sognare → sognato *dream of*	scégliere → scélto *choose*		
suonare → suonato *sound*	scéndere → scéso *descend*		
tagliare → tagliato *cut*	scrìvere → scritto *write*		
trovare → trovato *find*	vìncere → vinto *win*		
usare → usato *use*	vìvere → vissuto *live*		

In selecting the items, verbs that might trouble patients (e.g., *morire* '*die*') were avoided, as were onomatopoeic verbs, recent borrowings, and verbs which may involve additional, complex morphological structure, such as reflexive verbs (e.g., *avvedersi* '*notice*'), and prefixed verbs for which the unprefixed form of the verb is a real word (e.g., *perseguire* '*pursue*', *seguire* '*follow*').

The real past-participle verbs consisted of 30 irregular verbs matched group-wise to 30 regular verbs on lemma frequency (irregular: 3.27; regular: 3.36; $t < 1$), frequency of the infinitive (irregular: 1.90; regular: 1.91; $t < 1$), and masculine singular past-participle frequency (irregular: 1.34; regular: 1.34; $t < 1$). Frequency matching was based on standard frequency counts (out of 496,000 words) (De Mauro, Mancini, Vedovelli, & Voghera, 1993); values were augmented by one and natural-log transformed prior to matching, as in previous studies (Ullman, 1999). The regular verbs in the past-participle task all belong to morphological class I (infinitive in –*are*), and form their past-participle by adding –*ato* to the infinitival stem (e.g., *port-are* → *port-ato* '*carry*'). The irregular verbs were primarily class II, but included 2 class III verbs. The infinitival forms of the regular and irregular verbs did not differ in length either orthographically (regular: 7.77; irregular: 7.87; $t < 1$) or phonologically (number of syllables: regular: 3.50; irregular: 3.43; $t < 1$).

The real present-tense items consisted of 16 irregular verbs and 16 regular verbs, matched on lemma frequency (irregular mean: 4.64; regular mean: 4.59; $t < 1$), frequency of the infinitive (irregular mean: 2.96; regular mean: 2.98; $t < 1$), and first person singular inflected form frequency (irregular mean: 1.84; regular mean: 1.73; $t < 1$). The regular verbs in the present-tense task were all drawn from morphological class I. The irregular verbs were taken from all three morphological classes (1 from class I, 7 from class II, 8 from class III). They were irregular in the first person singular either by changing the present-tense stem in an unpredictable way (*usc-ire* → *èsc-o*; $n = 8$), or through the addition of a stem augment (e.g., *ven-ire* → *ven-g-o*; $n = 8$). Note that *bére* and *dire* were both classified as irregular verbs because the present-tense stem is not predictable from the infinitival form for either verb. In contrast to the past-participles, the regular present-tense infinitives were actually *longer* than the irregular present-tense infinitives, both orthographically (regular: 7.25; irregular: 6.06; $t(30) = 2.66$, $p = 0.01$), and phonologically (number of syllables: regular: 3.38; irregular: 2.88; $t(30) = 2.83$, $p = 0.008$). Thus if length has any effect at all, it would be expected to make regulars harder, biasing the stimuli against an irregular deficit.

Finally, we examined whether the regular and irregular verbs differed on consonant density, calculated as the number of consonants divided by the number of syllables of a given form. This measure captures important aspects of the phonological complexity of the verb forms (Bird, Lambon Ralph, Seidenberg, McClelland, & Patterson, 2003; Joanisse & Seidenberg, 1999; McClelland & Patterson, 2002; Ullman et al., 1997), while avoiding the potential confound of any phonological length differences between regulars and irregulars. The regular and irregular verbs did not differ on consonant density for either the past-participle or present-tense items, on either their infinitival forms (past-participle items: regular: 1.14, irregular: 1.14; $t(58) < 1$; present-tense items: regular: 1.06, irregular: 0.99; $t(30) = 1.12$, $p = 0.27$) or their inflected forms (past-participle items: regular: 1.14, irregular: 1.21; $t(58) < 1$; present-tense items: regular: 1.09, irregular: 1.18; $t(30) < 1$).

[a] Takes augment.

vs. 99.5%; $t_1(11) = 2.91$, $p = 0.01$; $t_{2s}(14.5) = 1.75$, $p = 0.10$), whereas the control subjects did not (irregular: 100.0%; regular: 100.0%). Between-subjects analyses showed that the pADs performed worse than controls at irregulars (92.8% vs. 100.0%; $t_{1s}(11) = 3.46$, $p = 0.005$; $t_2(14) = 1.90$, $p = 0.08$), but not regulars (99.5% vs. 100%; $t_{1s}(11) = 1.00$, $p = 0.34$; $t_2(15) = 1.00$, $p = 0.33$). The interaction (pAD/control × regular/irregular) confirmed the relative deficit of the pAD patients at irregulars (ANOVA: $F_1(1,22) = 9.72$, $p = 0.005$; $F_2(1,29) = 3.25$, $p = 0.08$).

This interaction remained in the by-subjects ANCOVA with residual MMSE scores covaried out ($F_1(1,21) = 4.97$, $p = 0.04$), and in the by-items ANCOVA with orthographic and phonological length covaried out ($F_2(1,27) = 2.92$, $p = 0.10$). Follow-up *t*-tests on the adjusted means from the by-subjects ANCOVA showed that, even with dementia held constant, the pADs performed worse than controls on irregulars (pAD: 93.2%; control: 99.5%; $t_1(21) = 3.51$, $p = 0.002$) but not on regulars (pAD: 99.4%; control: 99.5%; $t_1(21) < 1$). Follow-up *t*-tests on the adjusted means from the by-items ANCOVA also confirmed the pAD patients' deficit at irregulars, with pADs performing worse on irregular than regular verbs (irregular: 92.4%, regular: 99.8%; $t_2(27) = 2.42$, $p = 0.02$), and no difference between the two verb types for controls (both adjusted means at 100%).

We separately examined the four class II infinitives that take a -*g*– augment (Table 2), since these augments may be rule-products (see Section 1). The pADs showed no trace of an interaction between the augment/non-augment irregulars and frequency-matched regulars ($F_1(1,11) = 1.12$, $p = 0.31$; $F_2(1,27) = 0.16$, $p = 0.69$). This suggests

Table 3
Novel verbs.

Class I infinitive	Class II infinitive
carlàre	dòrcere
cregnàre	ammìngere
darmàre	stèngere
delàre	collèndere
galzàre	stèrgere
gloppàre	ciòlgere
nestràre	risciùmere
nissàre	nìggere
scaràre	nùngere
scumàre	lùdere
sfolpàre	incròdere
sporiàre	affèrdere
stainàre	decùtere
stommàre	nòrgere
tagnàre	contrìmere
trigàre	schìdere

We created 16 novel class II verbs, with infinitives in *–ere*, and 16 novel class I verbs, with infinitives in *–are*. Word stress was indicated with accent marks—on the root for class II novel verbs (i.e., irregularly accented), and on the thematic vowel *-a-* for class I novel verbs. While stress is not normally indicated on the thematic vowel *-a-* for real regular verbs (i.e., it is a regular stress pattern), we explicitly marked stress to make it clear that the novel regular verbs were not (intended to be) irregular in any way.

The novel class II verbs were created to encourage irregularization. Each novel infinitive rhymed with the infinitives of at least five real class II verbs that had irregular *past-participles*, while rhyming with no class I or class III verbs ("rhyming" is defined here as sharing the phonemes of the rime – i.e., nucleus and coda – of the final syllable of the infinitival stem, taking stress into account as well). The novel class I verbs were designed to rhyme with at least five real class I verbs, and no class II or class III verbs (in some cases, one existing class II or class III rhyming verb was allowed, if this rhyming verb was felt to be rare or very rare, based on native speaker judgment). The novel class I and class II verbs were then matched one-to-one based on the largest number of existing rhyming verbs that form their past-participles in the same way. For example, of the 25 existing class II verbs that end in *–ingere*, 20 of 25 are in a cluster that have past-participles ending in *–into* (e.g., *fingere* → *finto*), while 5 of 25 are in a cluster that have past-participles ending in *–etto* (e.g., *stringere* → *stretto*). Thus the novel class II verb *ammingere* was considered to have 20 irregular rhyming verbs (with *–into* past-participles), and was thus matched to the novel regular *cregnare*, which rhymes with 20 regular class I verbs. Novel class I and their matched novel class II verbs are displayed in the same row in the table. The novel class II verbs were shorter than their matched novel class I verbs, both orthographically (class I: 7.38; class II: 8.19; $t_s(22.2) = 2.37$, $p = 0.03$) and phonologically (number of syllables: class I: 3.06; class II: 3.44; $t_s(21.8) = 2.63$, $p = 0.02$); see Section 2.6 for discussion of the inclusion of these length differences as covariates in statistical analyses. Finally, the measure of consonant density used for the real verbs (see Table 2) did not differ between the class I and class II infinitives (respectively, 1.29 vs. 1.25, $t(30) < 1$). Note that we did not calculate consonant density for inflected forms of novel verbs because more than inflected form a given verb is possible.

None of the novel verbs were created to be irregularized in the present-tense. In fact, none of the class I or class II novel verbs rhymed with real verbs that are irregular in the first person singular present-tense. Moreover, none of the novel class II verbs had the appropriate stem phonology for the addition of a *-g-* augment – i.e., a stem ending in /l/, /ʎ/, /n/, or /ɲ/ (spelled *–l-*, *-gl-*, *-n-*, and *-gn-*, respectively).

that the *-g*-augments on class II verbs are not added to present-tense forms by a default rule, but rather may depend on a memorized representation in the lexicon.

3.3. Novel past-participle

On novel past-participles (Table 4C), the pADs produced fewer irregularizations on novel class II verbs (e.g., *schìdere*) than regularizations on novel class I verbs (e.g., *delare*): 70.3% vs. 94.3%; $t_1(11) = 3.75$, $p = 0.003$; $t_{2s}(17.1) = 6.10$, $p < 0.0001$. The irregularization/regularization difference was also significant for the control subjects (91.7% vs. 99.5%; $t_1(11) = 2.07$, $p = 0.06$; $t_{2s}(17.8) = 4.39$, $p = 0.0004$). Between-groups comparisons showed that the pADs produced significantly fewer irregularizations of class II verbs than controls (70.3% vs. 91.7%; $t_{1s}(15.6) = 2.14$, $p = 0.05$; $t_2(15) = 5.73$, $p < 0.0001$). The pADs also performed worse than the controls on regularizations of class I verbs, though the difference was not significant by subjects (94.3% vs. 99.5%; $t_{1s}(11.2) = 0.91$, $p = 0.38$; $t_2(15) = 5.00$, $p = 0.0002$). Crucially, the interaction (pAD/control × regularization/irregularization) was significant ($F_1(1,22) = 4.74$, $p = 0.04$; $F_2(1,30) = 17.43$, $p = 0.0002$), indicating that the drop in performance for the pADs was larger for the class II than class I verbs.

This interaction remained significant in the by-items ANCOVA with orthographic and phonological length covaried out ($F_2(1,28) = 33.75$, $p < 0.0001$). Follow-up comparisons of the orthographic- and phonological-length-adjusted means revealed the same pattern as on the unadjusted means: both the pADs and the controls were significantly worse at irregularizations than regularizations, although the difference for pADs (67.6% vs. 97.0%; $t_2(28) = 9.49$, $p < 0.0001$) was much larger than for controls (92.0% vs. 99.1%; $t_2(28) = 2.29$, $p = 0.03$).

3.4. Novel present-tense

The pADs performed worse (that is, produced fewer *regularizations*; see pretest in Section 2.4) on the class II than class I verbs (78.6% vs. 88.0%; Table 4D), with this difference significant by items and marginally significant by subjects ($t_1(10) = 1.99$, $p = 0.07$; $t_2(30) = 2.76$, $p = 0.01$). The control subjects did not differ on the two verb types (class II: 99.5%; class I: 99.5%). Relative to controls, the pADs produced fewer regularized responses on class II verbs ($t_{1s}(11.1) = 2.61$, $p = 0.02$; $t_2(29) = 2.35$, $p = 0.02$), whereas this difference was not reliable for class I verbs ($t_{1s}(11.2) = 2.27$, $p = 0.04$; $t_2(29) = 1.00$, $p = 0.33$). The interaction (pAD/control × regular/irregular) was significant by items, and approached significance by subjects ($F_1(1,22) = 3.96$, $p = 0.06$; $F_2(1,30) = 8.05$, $p = 0.008$). ANCOVAs were not conducted, as no factors met criteria for inclusion as covariates (see Section 2.6).

3.5. Errors

Previous studies of elicited English past-tense production report consistent patterns of errors in patients with temporal-lobe damage (Cortese et al., 2006; Patterson et al., 2001; Ullman, in press; Ullman et al., 1997, 2005). Across patient groups, over-regularizations (e.g., *dig* → *digged*) constitute the preponderance of errors on real irregulars, though unmarked forms (e.g., *dig* → *dig*) are common, and irregularizations (e.g., *dig* → *dag*) are also produced. For novel irregular verbs (e.g., *spling*), temporal-lobe patients largely produce regularizations (*splinged*), with a much smaller number of irregularizations (*splang, splung*), and a few unmarked forms (*spling*) and substitutions (i.e., "word intrusions" such as *spling* → *sprang*) (Ullman, in press; Ullman et al., 2005). In contrast, real and novel regulars yield few errors in temporal-lobe patients, other than small numbers of unmarked forms (*walk, plag*), and (for novels) a few irregularizations (*plog*), phonological distortions (*pragged*), and substitutions (*plucked*).

Here we examine major categories of possible and actual errors produced in the current study (see Table 4); note that unmarked forms (i.e., without an agreement affix) are not possible in Italian, and no subjects omitted an agreement affix on any response.

Regularization errors on irregular verbs were defined as the infinitival stem + *–ato* for real and novel past-participles (e.g., *giùngere* → *giungato*; *schidere* → *schidato*), and the infinitival stem + *-o* for real present-tenses (e.g., *uscire* → *usco*). Unlike in English, the Italian-speaking pADs did not produce more regularization errors than the controls for any of the three relevant conditions (Table 4A–C).

Irregularization errors were defined as errors containing stem-changes similar to those found among real irregular forms—for example, the irregularization *diriso* instead of the correct *dirètto* as the past-participle of the irregular *dirìgere* ("*to direct*"), or *uscisco*

Table 4
Responses in the past-participle and present-tense elicitation tasks for pAD patients and normal controls.

	pAD patients	Controls	*t*-Test
A. Real past-participle			
Regular (e.g., *domandare*)			
Correct (*domandato*)	99.7% (0.3)	100% (0)	(see text)
Substitution error (*chiesto*)	0.3% (0.3)	0	$t_{1s}(11) = 1.00$, $p = 0.34$; $t_2(29) = 1.00$, $p = 0.33$
Irregular (e.g., *giùngere*)			
Correct (*giunto*)	95.3% (1.4)	99.4% (0.7)	(see text)
Irregularization error (*giutto*)	1.1% (0.5)	0	$t_{1s}(11) = 2.35$, $p = 0.04$; $t_2(29) = 1.68$, $p = 0.10$
Inflection error (*giunte*)	0.3% (0.3)	0	$t_{1s}(11) = 1.00$, $p = 0.34$; $t_2(29) = 1.00$, $p = 0.33$
Substitution error (*arrivato*)	1.9% (0.6)	0.6% (0.7)	t_1 (22) = 1.87, p = 0.08; $t_2(29) = 1.22$, $p = 0.23$
Phonological distortion (*gunto*)	0.3% (0.3)	0	$t_{1s}(11) = 1.00$, $p = 0.34$; $t_2(29) = 1.00$, $p = 0.33$
Other error (*giùngere*)	1.4% (0.6)	0	$t_{1s}(11) = 2.16$, $p = 0.05$; $t_2(29) = 1.72$, $p = 0.10$
B. Real present-tense			
Regular (e.g., *provare*)			
Correct (*provo*)	99.5% (0.5)	100% (0)	(see text)
Other error (*provare*)	0.5% (0.5)	0	$t_{1s}(11) = 1.00$, $p = 0.34$; $t_2(15) = 1.00$, $p = 0.33$
Irregular (e.g., *tenere*)			
Correct (*tèngo*)	92.7% (2.1)	100% (0)	(see text)
Regularization error (*teno*)	1.1% (1.1)	0	$t_{1s}(11) = 1.00$, $p = 0.34$; $t_2(14) = 1.47$, $p = 0.16$
Inflection error (*tiène*)	1.1% (0.7)	0	$t_{1s}(11) = 1.48$, $p = 0.17$; $t_2(14) = 1.29$, $p = 0.22$
Future tense error (*terrò*)	1.1% (0.7)	0	$t_{1s}(11) = 1.48$, $p = 0.17$; $t_2(14) = 1.00$, $p = 0.33$
Substitution error (*vado*)	3.3% (1.7)	0	$t_{1s}(11) = 1.91$, $p = 0.08$; $t_2(14) = 1.87$, $p = 0.08$
Other error (*tenere*)	1.1% (0.7)	0	$t_{1s}(11) = 1.48$, $p = 0.17$; $t_2(14) = 1.00$, $p = 0.33$
C. Novel past-participle			
Class I (e.g., *delàre*)			
Regularized (*delato*)	94.3% (5.7)	99.5% (0.7)	(see text)
Irregularization error (*delatto*)	0	0.5% (0.7)	$t_{1s}(11) = 1.00$, $p = 0.34$; $t_2(15) = 1.00$, $p = 0.33$
Substitution error (*delegato*)	3.1% (3.1)	0	$t_{1s}(11) = 1.00$, $p = 0.34$; $t_2(15) = 3.00$, $p = 0.009$
Other (*delare*)	2.6% (2.6)	0	$t_{1s}(11) = 1.00$, $p = 0.34$; $t_2(15) = 2.61$, $p = 0.02$
Class II (e.g., *schìdere*)			
Irregularized (*schiso/schisso*)	70.3% (9.0)	91.7% (2.8)	(see text)
Regularized (*schidato*)	12.0% (6.6)	7.8% (2.7)	t_1 (22) = 0.53, $p = 0.60$; $t_2(15) = 2.07$, $p = 0.06$
Inflection error (*schise*)	1.0% (1.0)	0	$t_{1s}(11) = 1.00$, $p = 0.34$; $t_2(15) = 1.46$, $p = 0.16$
Substitution error (*mangiato*)	6.3% (4.1)	0	$t_{1s}(11) = 1.51$, $p = 0.16$; $t_2(15) = 5.20$, $p = 0.0001$
Phonological distortion (*scheso*)	7.3% (2.5)	0.5% (0.7)	$t_{1s}(11.9) = 2.62$, $p = 0.02$; $t_2(15) = 2.78$, $p = 0.01$
Other (*sclicco*)	5.7% (4.1)	0	$t_{1s}(11) = 1.40$, $p = 0.19$; $t_2(15) = 3.91$, $p = 0.001$
D. Novel present-tense			
Class I (e.g., *carlàre*)			
Regularized (*carlo*)	88.0% (5.0)	99.5% (0.7)	(see text)
Inflection error (*carla*)	3.1% (2.6)	0	$t_{1s}(11) = 1.20$, $p = 0.26$; $t_2(15) = 2.42$, $p = 0.03$
Future tense error (*carlerò*)	0.5% (0.5)	0	$t_{1s}(11) = 1.00$, $p = 0.34$; $t_2(15) = 1.00$, $p = 0.33$
Substitution error (*mangio*)	4.7% (3.6)	0	$t_{1s}(11) = 1.30$, $p = 0.22$; $t_2(15) = 4.39$, $p = 0.0005$
Phonological distortion (*chirlo*)	1.0% (1.0)	0.5% (0.7)	$t_{1s}(16.2) = 0.45$, $p = 0.66$; $t_2(15) = 1.00$, $p = 0.33$
Other error (*carlare*)	0.5% (0.5)	0	$t_{1s}(11) = 1.00$, $p = 0.34$; $t_2(15) = 1.00$, $p = 0.33$
Class II (e.g., *contrìmere*)			
Regularized (*contrimo*)	78.6% (8.0)	99.5% (0.7)	(see text)
Inflection error (*contrimete*)	4.2% (4.2)	0.5% (0.7)	$t_{1s}(11.3) = 0.87$, $p = 0.40$; $t_2(15) = 3.42$, $p = 0.004$
Future tense error (*contrimerò*)	3.6% (2.7)	0	$t_{1s}(11) = 1.34$, $p = 0.21$; $t_2(15) = 3.42$, $p = 0.004$
Substitution error (*comprimo*)	7.3% (4.5)	0	$t_{1s}(11) = 1.61$, $p = 0.14$; $t_2(15) = 4.87$, $p = 0.002$
Phonological distortion (*contrigo*)	3.6% (1.4)	0	$t_{1s}(11) = 2.55$, $p = 0.03$; $t_2(15) = 2.78$, $p = 0.01$
Other error (*contrìmere*)	2.6% (2.6)	0	$t_{1s}(11) = 1.00$, $p = 0.34$; $t_2(15) = 2.61$, $p = 0.02$

Mean percentage of different types of responses, with standard errors in parentheses. Percentages may not add up to 100% due to rounding. Responses were categorized as (1) correctly inflected forms for real verbs; (2) regularizations of novel verbs or of real irregular verbs (stem + *-ato* for past-participles or stem + *-o* for present-tense); (3) irregularizations of real or novel verbs; (4) inflection errors (forms with the correct stem but a grammatically incorrect – that is, task inappropriate – inflectional ending); (5) future tense errors, for present-tense production only (the future tense form of the given verb; note that the future tense in Italian can be used to express uncertainty or doubt about a present event, and thus, unlike an inflection error, is not inconsistent with the grammatical context of the present-tense presentation sentence); (6) substitution errors (real verbs with correct – that is, task-appropriate – inflection); (7) phonological distortions (non-word errors that were not regularizations or irregularizations, and did not differ by more than three phonemes from the correct or expected response); and (8) other errors, such as failures to respond, stimulus repetitions (e.g., the infinitival form), responses to previously presented stimuli, or responses that could not otherwise be categorized. Errors are not listed in the table if no subject in either group made any errors of that type for a given condition.

instead of *èsco* as the present-tense form of the irregular verb *uscire* (“*to go out*”). The pADs produced more irregularization errors on real irregular past-participles than the controls (Table 4A); note that infinitival stems affixed with *–uto* were in principle categorized as irregularization errors, though no such forms were produced. No irregularization errors were made by either subject group on real irregulars or novel class II verbs in present-tense production. Real regular and novel class I verbs yielded no irregularizations for the pAD subjects for either past-participle or present-tense, and a very small number of irregularizations for control subjects, only among the novel past-participles, though the rate of these errors (0.5%) was not statistically different from zero ($t_0(11) = 1.00$, $p = 0.34$).

Phonological distortions were defined as non-word forms that were not regularizations or irregularizations, and whose stems did not differ by more than three phonemes from the stem of the correct or expected response. The pAD patients made significantly more phonological distortion errors than control subjects for the novel class II past-participle and present-tense items (Table 4C and D). On real irregular past-participles, only the pADs made phonological distortion errors, although at a rate not significantly different than zero ($t_0(11) = 1.00$, $p = 0.34$). No such errors were made by either subject group on real irregular or regular present-tense verbs, and while both groups made a small number of these errors for novel class I present-tenses, there was no significant group difference. Finally, when phonological distortion errors were made, the pADs produced somewhat more of them to irregular/class II verbs than to regular/class I verbs. This difference was significant for novel past-participles (7.3% vs. 0%; $t_1(11) = 2.88$, $p = 0.02$; $t_{2s}(15) = 3.22$, $p = 0.006$), approached significance by items for novel present-tenses (3.6% vs. 1.0%; $t_1(11) = 1.33$, $p = 0.21$; $t_{2s}(23.1) = 1.75$, $p = 0.09$), but was not significant for real past-participles (0.3% vs. 0%; $t_1(11) = 1.00$, $p = 0.34$; $t_{2s}(29) = 1.00$, $p = 0.33$).

Substitutions were defined as a correctly inflected past-participle form (in past-participle production) or present-tense form (in present-tense production) of a real verb other than the given verb. Substitution rates were somewhat higher for the pADs than controls for each of the real irregular and novel class II conditions (Table 4). Additionally, the pADs produced a significantly larger number of substitution errors to real irregular than regular verbs (ANOVA main effect, across past-participle and present-tense conditions; irregular: 2.6%; regular: 0.1%; $F_1(1,11) = 7.26$, $p = 0.02$, $F_2(1,88) = 4.71$, $p = 0.03$), and to novel class II than class I verbs (ANOVA main effect, again across past-participle and present-tense conditions; class II: 6.8%; class I: 3.9%; $F_1(1,11) = 9.03$, $p = 0.01$, $F_2(1,60) = 5.55$, $p = 0.02$).

Across all real verbs in both tasks, 25% of the substitution errors were semantically but not phonologically similar to the stimulus (e.g., *sapere* "*to know*" → *conosco* "*(I) know*" instead of *so*), 38% were phonologically but not semantically similar (e.g., *vivere* "*to live*" → *visto* "*seen*" in place of *vissuto*), and 19% were both semantically and phonologically similar (e.g., *venire* "*to come*" → *vado* "*(I) go*" instead of *vengo*). For the novel verbs (again across all verbs in both tasks), 24% of the errors were phonologically similar to the stimulus (e.g., *carlare* → *scarlato* "*disentangled*"), with the remaining errors bearing no obvious relation to the stimulus (note that the semantic appropriateness of substitutions to their sentence contexts was not examined).

4. Discussion

In summary, the evidence suggests that Italian-speaking pAD patients are impaired at the production of correct or expected past-participle and present-tense forms of real irregular and novel class II verbs. In contrast, the pADs were completely spared at the production of real regular past-participle and present-tense forms (i.e., class I regulars; note that class II and III regulars were not examined), and were not reliably different from control subjects at regularizing novel class I verbs.

These findings were not explained by a variety of potentially confounding factors, including subject age, education, dementia, sex, or handedness, as well as the item-level variables of lemma frequency, infinitival frequency, inflected-form frequency, infinitival orthographic length, infinitival phonological length, and both infinitival and inflected-form consonant density (see Section 2.6 and Tables 2 and 3). The pattern is also unlikely to be explained by imageability or other semantic differences between items; although such factors were not explicitly controlled for among the real items, they are not likely to contribute to the pattern observed among the novel verbs, which paralleled that of the real verbs, suggesting common underlying mechanisms.

It might be argued that the lack of a similar regular/irregular accuracy difference between the pAD and control subjects might be explained by ceiling effects, particularly among the control subjects. The controls were at ceiling on both regulars and irregulars in three of the four conditions (real past-participle, real present-tense, novel present-tense); additionally, the pAD patients were at ceiling at regulars in the two real verb conditions. However, this does not seem to fully account for the pAD patients' relative deficit at irregulars. First, these ceiling effects do not affect the conclusion that the pAD patients were worse than the controls at producing irregularly inflected forms, a difference which was significant in all four conditions. Second, in all four conditions the patients were *not* reliably worse than the controls at producing regulars, and the regular/irregular by patient/control interactions were significant. Third, elderly and other healthy adult subjects consistently show perfect or near-perfect performance at the production of regulars, not just in Italian, but also in English (Cortese et al., 2006; Ullman, in press; Ullman et al., 1997, 2005). Thus it is reasonable to consider the controls' performance at regulars not as a ceiling effect, but rather as a reflection of normal language. Finally, ceiling effects cannot of course explain differences between the pAD and control groups on the types of errors made (see below for discussion). Thus ceiling effects do not appear to fully account for the observed pattern of effects.

It might also be suggested that the repetition of the regular pattern – i.e., infinitival stem + affix – within each task might have resulted in improved performance for the pAD patients on regulars. Over all items, this might have led to the appearance of a greater impairment at the production of irregular than regular forms.

First, we compared performance on the regular items that were presented earlier in the task with those presented later in the task (separately for the present-tense and past-participle tasks). For the past-participle task, over all regular verbs (i.e., real regulars and novel class I verbs), accuracy on the first third of items (98%) was no different than on the last third (98%; $t_1 < 1$; $t_2 < 1$). Moreover, a correlation between accuracy and item-order over all items (i.e., not excluding the middle third of items, avoiding power loss and related problems when dichotomizing a continuous variable; MacCallum, Zhang, Preacher, & Rucker, 2002) was not significant ($r(44) = -.016$, $p = 0.91$). For just the novel class I verbs, for which performance was not as close to ceiling, and which therefore may be more revealing of these sorts of repetition effects, there was again no difference in accuracy between the first and last third of items (96% vs. 95%; $t_1 < 1$; $t_2 < 1$), and the correlation between accuracy and item order was again non-significant ($r(14) = .017$, $p = 0.95$). The present-tense task showed the same pattern. Over all regular verbs (i.e., real regulars and novel class I verbs), performance on the first and last third of items did not differ (93% vs. 94%; $t_1 < 1$; $t_2 < 1$), and the correlation between performance and item-order was not significant ($r(30) = .107$, $p = 0.56$). Similarly, the novel class I verbs showed no reliable difference between the first and last third of items (85% vs. 90%; $t_1 < 1$; $t_2 < 1$), and no correlation of accuracy with item-order ($r(14) = .224$, $p = 0.40$). Thus there is no evidence that performance on regulars improved during the task.

Second, we examined whether performance at regulars differed for regulars that immediately followed another regular item, as compared to those that followed an irregular item—that is, whether an immediate repetition of the regular pattern may have helped performance. For the past-participles, the pAD patients performed identically on regulars/class I verbs that were preceded by another regular/class I verb and those preceded by an irregular/class II verb, both over all items (98% vs. 98%; $t_1 < 1$; $t_2 < 1$), and over just the novel class I items (95% vs. 94%; $t_1 < 1$; $t_2 < 1$). For present-tense, the patients performed slightly *worse* on regulars/class I verbs preceded by another regular item than on those preceded by an irregular (92% vs. 97%; $t_1(11) = 1.85$, $p = 0.09$; $t_2(30) = 1.30$, $p = 0.20$). Indeed, for just the novel class I verbs, the patients showed reliably worse performance when the verb was preceded by a regular than an irregular item (83% vs. 94%; $t_1(11) = 2.60$, $p = 0.02$; $t_2(14) = 2.29$, $p = 0.04$). Thus, if repetition of the regular pattern had any effect at all, it lowered rather than enhanced performance on the regular items.

A third possible concern with the pattern of results is the relatively small effect size observed for the irregular deficits on the real items (note however that the effect size on the novel items was much larger). At this point it is not clear why the real irregular deficit was relatively small (though statistically significant). This could reflect the fact that the patients were, on average, relatively well educated, and all patients were at an early stage of the disease. In addition, task- or item-related factors may have played a role. A pilot version of the study, which used a slightly different set of items and was tested on an entirely different set of patients and age- and education-matched controls, reported a larger irregular deficit for the real verbs than was found in the current study: the patients showed a deficit of 10.2% as compared to controls on real irregular past-participles (as compared to 4.1% here), and 20% on real irregular present-tense forms (as compared to 7.3% here) (Cappa & Ullman, 1998). This suggests that the effect size for real irregulars is in fact not always small.

Fourth, it might be argued that type and/or token frequency differences between the regular and irregular inflectional patterns could explain the observed irregular deficit. Over all past-participle forms in Italian, the class I regular pattern (stem + *-ato*) is the most common both by type frequency (the number of verbs that use each pattern—i.e., counting each verb once) and token frequency (how frequently each pattern is used—i.e., counting each verb multiple times) (Colombo, Stoianov, Pasini, & Zorzi, 2006). For the present-tense, the regular pattern (stem + *-o*; used for all three morphological classes) also has the highest type and token frequency. If, for example, pAD patients simply had trouble with the less frequent pattern, it could explain the finding that the patients showed a deficit on the real irregular past-participles, real irregular present-tenses, and novel irregular past-participles. However, such an account does not seem to explain the pattern of spared class I regularizations but deficient class II regularizations seen for the novel present-tense items.

Finally, with respect to the deficit found for regularized responses to novel class II present-tense verbs, it might be argued that the irregular stress pattern in these infinitives (i.e., stress on a syllable other than the penultimate; Laganaro, Vacheresse, & Frauenfelder, 2002) may have been difficult for the patients, leading to worse performance on these verbs. Indeed, evidence from unimpaired individuals of longer reading times for irregularly stressed words (nouns and adjectives) is consistent with greater difficulty reading these forms than regularly stressed forms (Colombo, 1992). In addition, studies of patients with left temporal-lobe damage (including aphasia, semantic dementia, and fluent primary progressive aphasia) have revealed impairments at the naming (i.e., picture naming), reading, and repetition of words with irregular stress patterns, relative to words with regular stress patterns (Cappa, Nespor, Ielasi, & Miozzo, 1997; Galante, Tralli, Zuffi, & Avanzi, 2000; Miceli & Caramazza, 1993; Rozzini, Bianchetti, Lussignoli, Cappa, & Trabucchi, 1997). However, Alzheimer's patients at mild and moderate stages of the disease were found to have no irregular stress deficits (at reading) relative to healthy controls (Colombo, Brivio, Benaglio, Siri, & Cappa, 2000), and thus it does not seem likely that a pAD difficulty with irregular stress could explain the observed pattern of results.

In sum, it does not appear that these potentially confounding factors provide a satisfactory account of the observed pAD deficit on irregular inflected forms. In what follows we discuss how existing models of morphological processing can account for this irregular deficit in Italian, and discuss which aspects of the data pose problems for these models.

4.1. Dual-system models

The pAD deficit at producing real irregular past-participle and present-tense forms and at irregularizing novel class II past-participles – a pattern that parallels the pAD deficit at producing real and novel irregular forms in English – is predicted by dual-system models such as the Declarative/Procedural model. On such a view, the production of real and novel irregular forms depends on a temporal-lobe based mental lexicon, which is dysfunctional in pAD.

However, other aspects of the data were not predicted by this account. First, the deficit at producing present-tense regularizations of novel class II verbs seems somewhat surprising, since regular inflection is predicted to be spared in pAD. Second, the relative dearth of regularization errors on irregular/class II verbs was not expected. Instead of such errors, the pAD patients made substitution, distortion, and irregularization errors at higher-than-expected rates.

Both of these surprising patterns may in fact be consistent with a dual-system model, in particular in which there is a lexical dysfunction related to morphological class. Because there are far more irregular verbs in class II than in class I in Italian, indication of membership in class II (i.e., the thematic vowel in the verb infinitive presented to the participants) may lead to a higher expectation of an irregular form, and hence a greater dependence on lexical memory for all class II verb forms.

One possibility is that a greater dependence on memory for class II verbs might lead to the memorization not only of irregular forms, but also of non-stem-change (i.e., regular) forms of class II verbs, consistent with some dual-mechanism claims (Caramazza, Laudanna, & Romani, 1988; Chialant & Caramazza, 1995; Say, 1999). If regular present-tense forms of class II verbs (e.g., *appendere* → *appendo*) are stored as whole forms, then regularized forms of novel verbs (*contrimere* → *contrimo*) could be produced through associative generalization in lexical memory (as has been found in English regular past-tense production in certain circumstances; Hartshorne & Ullman, 2006). Thus lexical deficits in pAD would be expected to impair the present-tense production not only of any irregular class II verb forms, but also any regular class II verb forms (note that no real class II verbs with regular present-tenses, such as *appendere* → *appendo* were tested in the current study).

Even if regular forms are not stored, a high expectation of an irregular form for any (real or novel) verb marked as class II could explain the deficit at producing present-tense regularizations of novel class II verbs, as well as the pattern of errors on class II verbs. Specifically, an expectation of an irregular should trigger a lexical search (or attempted generalization in associative memory) for a stored form. In the disordered lexical memory of pAD, this search could lead to (false positive) lexical errors (including the retrieval of incorrect forms leading to substitution errors, and inappropriate associative generalizations leading to phonological distortions or irregularization errors) which would moreover block application of the default grammatical rule (for a similar claim, see Colombo et al., 2006). This would result in lower accuracy for both real and novel class II verbs, as well as the observed pattern of errors.

Note that the lack of irregularization errors among real irregular and novel class II present-tense items could be due to weak phonological clustering in irregular first person singular present-tense forms, or the preponderance of other types of errors, such as substitution errors. Additionally, the lack of phonological similarity between the novel class II items and existing irregular present-tense forms in Italian (as these novel verbs were not constructed to be similar to existing verbs with irregular present-tenses; Table 3) should contribute to the lack of irregularization errors among novel present-tense forms. Finally, the lack of regularizations may be explained by the greater complexity of the inflectional paradigm in Italian. Many Italian irregular verbs have multiple irregular forms, whereas most English irregular verbs have only one or two (past-tense and/or past-participle), potentially leading to a more complex lexical search in Italian, and thus to the possibility of more lexical errors. For a similar point and related findings, see Bates et al. (1987) and Bates and Goodman (1997).

4.2. Single-mechanism models

Single-mechanism models of language that posit a dissociation between phonology and semantics also predict an irregular deficit on real verbs for patients with temporal-lobe damage. Specifically, an impairment of real irregular past-participle and present-tense forms is consistent with the claim that these forms depend especially on temporal-lobe based semantic representations that are damaged in pAD (Joanisse & Seidenberg, 1999). However, other aspects of the current data may be problematic for this approach.

First, the complete sparing of real regular inflected forms seems somewhat surprising from this perspective, given that the production of real regular forms is also posited to depend on semantics, albeit less so than irregulars. Indeed, the reported simulation of semantic damage to the model led to deficits of real regulars (even though the deficit was less severe than that of real irregulars) (see Fig. 4 in Joanisse & Seidenberg, 1999).

Second, the pAD deficit at class II as compared to class I novel verbs has not been predicted by the model, which has explicitly addressed novel regulars but not novel irregulars (Joanisse & Seidenberg, 1999; McClelland & Patterson, 2002). Moreover, a straightforward interpretation of the claim that novel inflection depends on phonology but not semantics (Joanisse & Seidenberg, 1999) predicts a different pattern, namely the relative sparing of *all* novel forms following damage to the semantic system (see Section 1 above). Note that if the model were to allow novel forms to depend on semantic representations, a deficit of novel irregulars as compared to novel regulars might be expected as a consequence of semantic damage, for the same reason that real irregulars are predicted to be more impaired than real regulars—namely that the phonological traces of irregulars are weaker than those of regulars (which have the advantage of a more common phonological pattern), and so depend relatively more on semantics. However, even though this might explain the deficit of novel irregulars observed elsewhere for English past-tense (Ullman, in press; Ullman et al., 2005) and in the current study for Italian past-participle inflection, it does not appear to account for the observed impairment in the production of (regular) class II novel present-tenses, which have the same (regular) phonological pattern as class I novel present-tenses. Additionally, the differences between the English and Italian error pattern would need to be explained. It remains to be seen whether future simulations of the model may in fact produce results consistent with these findings.

5. Conclusions

In sum, the results from the present study replicate important aspects of previous findings from the study of English inflection, and extend them to a language with a far more complex morphological system. The data suggest that the basic regular/irregular distinction, and the impairment of lexically based real and novel irregular inflection in temporal-lobe patients, holds cross-linguistically. In addition, the data clarify the neurocognitive nature of (ir)regularity across languages, and suggest that lexically based processing underlies not only individual irregular forms, but at least to some extent, also extends to predictable transformations for members of morphological classes which themselves contain many irregular verbs.

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