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RESEARCH ARTICLE

Resolving the problem of surface dyslexia in Italian through inflection of irregular verbs

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Abstract

Surface dyslexia and dysgraphia are considered diagnostic features of semantic variant primary progressive aphasia (svPPA) and are useful signs in English, a language whose attributes afford numerous opportunities to observe these phenomena. This, however, is not the case in many languages, including Italian, that have high transparency between orthography and phonology, making surface reading and spelling errors scarce. This creates a problem in applying the diagnostic recommendations for svPPA in such languages. Surface dyslexia and dysgraphia are examples of 'regularization' errors in which semantic knowledge loss leads to a failure to recognize exceptions that do not follow standard rules of pronunciation. Another form of regularization involves the incorrect inflection of irregular verbs using the rules that govern regular verbs. Unlike irregularly pronounced words, Italian, as with many languages, has numerous irregular verbs. The Italian Verb Inflection Test (IVIT) was developed to test the hypothesis that svPPA would regularize irregular verbs when inflecting them into two Italian past tenses. Results confirmed that people with svPPA made a significantly greater proportion of regularization errors compared to people with typical Alzheimer's disease or logopenic variant PPA. Without recourse to the other diagnostic features of PPA subgroups, the IVIT on its own could separate svPPA from these other two groups with 70% sensitivity and ~80% specificity. Regularization

of irregular verb inflection offers a solution to the problem of applying the surface dyslexia/dysgraphia criterion for svPPA diagnosis in Italian.

KEYWORDS

language, progressive aphasia, regularization, semantic dementia, semantics, surface dyslexia, verb inflection

INTRODUCTION

Surface dyslexia is a hallmark of semantic variant primary progressive aphasia (svPPA) (Gorno-Tempini et al., 2011; Hodges et al., 1992). It arises because progressive loss of semantic knowledge leads to patients failing to recognize words by their meaning while still being able to follow overlearned rules that translate orthographical representations to phonology. In svPPA, degradation of semantics means that 'irregular' words (those not obeying the rules of orthography to phonology) are pronounced according to orthographical rules; for instance, the irregular word *pint* may be mispronounced so as to rhyme with the 'regular' word, *hint*. The English language has an abundance of words lacking orthography to phonology correspondence, making surface dyslexia—and related surface dysgraphia—a useful clinical sign. As a consequence, surface dyslexia/dysgraphia was incorporated into the diagnostic recommendations for PPA subtypes (Gorno-Tempini et al., 2011).

Many languages, however, have high transparency between orthography and phonology, meaning that it is difficult to find words that are not pronounced as they are spelled, hence making clinical testing for surface dyslexia problematic. A potential solution in such languages may be found in noting that surface dyslexia/dysgraphia can be considered just one example of a 'regularization' error in which loss of semantic knowledge leads to faulty reliance on overlearned rules. Thus, rather than trying to identify surface reading errors in languages that lack English's high percentage of irregularly pronounced words, a potential solution is to identify other forms of regularization error that may be more abundant in the target language. Verbs, for instance, can be inflected according to rules such as, in English, adding *-ed* to form the regular past participle (*I walk* ➔ *I walked*), but there are also irregular verbs that violate this rule (e.g. *I buy* ➔ *I bought*). SvPPA patients are known to make regularization errors (e.g. *I buy* ➔ *I buyed*) when making this inflection (Patterson et al., 2001). It was previously shown that when inflecting irregular verbs, German svPPA patients made an excess of regularization errors compared to those with other forms of PPA or typical (amnestic) Alzheimer's disease (tAD) (Billette et al., 2020). Consequently, it was proposed that verb inflection 'regularization' could replace the surface dyslexia/dysgraphia criterion in the diagnostic recommendations for classification of PPAs, thus making them more universally applicable across different languages.

A previous case study of svPPA proposed that errors in pronouncing words with unpredictable stress in Italian could substitute for surface dyslexia (Rozzini et al., 1997); this finding with stress pronunciation was subsequently also demonstrated in two stroke patients (Folegatti et al., 2015). We hypothesized that regularization could also be demonstrated with irregular verb inflection in Italian and would have diagnostic utility for distinguishing svPPA from tAD or other forms of PPA.

PATIENTS AND METHODS

Participants

We included patients who fulfilled criteria for Primary Progressive Aphasia (PPA) (Mesulam, 2001) or tAD (McKhann et al., 2011). PPA was further classified as svPPA or nonfluent variant PPA (nfvPPA)

using Gorno-Tempini et al.'s criteria (Gorno-Tempini et al., 2011). Logopenic variant PPA (lvPPA) was defined where the predominant deficit was word finding difficulty, after ruling out semantic or non-fluent variants. Exclusion criteria were less than 8 years of schooling, a history of stroke, brain tumour, brain injury, major psychiatric disorders, learning disability and presence of large or numerous vascular lesions on magnetic resonance imaging (MRI) brain scan. We included 10 patients with svPPA, 11 with lvPPA, five with nfvPPA and 20 with tAD. The diagnosis was supported by MRI in all cases and also by brain [^{18}F]-Fluorodeoxyglucose Positron Emission Tomography in 16/26 PPA cases and 17/20 tAD cases. Cerebrospinal fluid biomarkers were available in 4/10 svPPA cases and 5/5 nfvPPA cases and were consistent with non-Alzheimer pathology in each instance; biomarkers, namely CSF, were also available in 8/11 lvPPA cases and 7/20 tAD cases and all were consistent with Alzheimer pathology. We also recruited 26 healthy individuals as controls (HCs). HCs had no cognitive symptoms or history of major neurological or psychiatric disorders and a Mini-Mental State Examination (MMSE) (Foderaro et al., 2022) score >26/30.

All participants were native Italian speakers.

PPA and tAD groups underwent a general neuropsychological battery including, in addition to MMSE, Attentional Matrices (Spinnler & Tognoni, 1987), forward and backward Digit span (Monaco et al., 2013), immediate and delayed recall of the Rey Auditory Verbal Learning Test (RAVLT) (Carlesimo et al., 1996), copy and recall of the Rey-Osterrieth Complex Figure (ROCF) (Caffarra et al., 2002), Letter and Category fluency (Costa et al., 2014), Picture naming (Laiacona et al., 2016) and the Frontal Assessment Battery (FAB) (Appollonio et al., 2005). PPA groups were also administered the Pyramids and Palm Trees test (PPT) (Gamboz et al., 2009) and the repetition subtest from the Aachener Aphasie Test (AAT) (Luzzatti et al., 1996).

The study was approved by ethics committees of involved institutions and was conducted with the understanding and written consent of each participant and in accordance with the World Medical Association Declaration of Helsinki.

Development and reliability of the Italian verb inflection test (IVIT)

Italian verbs are divided into three conjugations defined by a specific ending of the infinitive form (*−are*, *−ere*, *−ire*), each characterized by a specific inflectional pattern. There are irregular verbs, however, that do not follow inflectional rules for the infinitive form to which they belong. The test required participants to inflect irregular verbs into two past tenses, the present perfect (*passato prossimo*) and preterite (*passato remoto*).

The breakdown of semantic knowledge in svPPA is known to be influenced by age of acquisition and word frequency—two inter-related concepts that are often referred to together as *cumulative frequency* (Ghyselinck et al., 2004; Lewis et al., 2001): svPPA preferentially leads to impairments in items with lower cumulative frequency. Moreover, ultra-high frequency items may be preserved even at late disease stages (e.g. one would not expect regularization inflecting the verb *to be* or to make a surface reading error with a word like *was*). Thus, both high and low frequency verbs were tested, with the predication that there would be more impairment on the low frequency items. For the same reason it was predicted that the preterite, being the less frequently used past tense in Italian, would be more impaired than the present perfect, analogous to German (Billette et al., 2020).

An initial version of the test was composed of 56 verbs: 14 High-Frequency (HF) regular verbs, 14 HF irregular verbs, 14 low-frequency (LF) regular verbs and 14 LF irregular verbs. The frequency of present perfect and preterite was determined using the Google search engine (Blair et al., 2002). This version of the IVIT was piloted in 26 healthy subjects. Seven of the 56 verbs were excluded because less than 70% of HCs were able to inflect them correctly and 13 were excluded in the process of rebalancing the number and frequency of regular and irregular verbs, leaving 36 items in the final test: nine HF regular verbs, nine HF irregular verbs, nine LF regular verbs and nine LF irregular verbs (the verbs and their individual and mean frequencies are listed in the Appendix in

the Supplementary material—Data S1). This final set of items showed very high reliability in its full form (Cronbach's alpha: .97) as well as, separately, in the present perfect (.95) and in the preterite (.96).

The test structure was the same as the German test (Billette et al., 2020). Items were shown at the center of a computer screen, with no time limit to respond and following four practice items. Each verb was presented in the present tense and third person singular conjugation within a simple, short sentence specifying the temporal context ('today he/she …') (Figure 1), using a blank space to prevent participants from adding extra words. Subjects were asked to read the present tense sentence aloud and then provide the present perfect for a second sentence beginning with 'yesterday' that showed the conjugated auxiliary verb and the preterite for a third sentence beginning with 'one year ago', without auxiliary verb; that is, in Italian, the presence of the auxiliary verb forces the participant to use the present perfect whereas its absence forces the use of the preterite. Precisely, instructions were as follows: '*Please read the first sentence aloud and then complete the second and third sentences with the correct verb tense. Remember to use the third person and the same verb for all sentences*'. Performance on the test was analysed in terms of the absolute number of errors, which were calculated separately for regular and irregular verbs. Errors for irregular verbs were subdivided into two categories: (1). regularizations and semiregularizations (see Figure 1 for an example); (2). nonregularization errors, which comprised a variety of errors, for example, wrong tense, wrong person or wrong verb, phonemic paraphasia, perseverations. The time of administration was approximately 10 mins.

Statistical analysis

All analyses were performed using SPSS 28.0 (SPSS Statistics for Windows, Armonk, NY: IBM Corp.). Shapiro–Wilk testing showed that data were not normally distributed, hence nonparametric statistics were used. Comparison of sociodemographic, clinical and neuropsychological features between study groups was performed with Kruskal–Wallis or chi-square tests for, respectively, continuous and categorical variables. The Kruskal–Wallis test was also used to compare the proportion of regularizations, expressed as the ratio of the number of regularizations divided by the number of nonregularization errors (higher values indicating a greater number of regularization than nonregularization errors). The accuracy of the ratio in distinguishing svPPA from the other study groups was assessed with Receiver Operating Characteristic (ROC) curve analysis, computing 95% CI of sensitivity and specificity at Youden index thresholds.

Performance on the IVIT was further investigated through Generalized Estimating Equations (GEE) analysis, using Wald's chi-square test for Type 3 contrasts, followed by post hoc comparisons. GEE assessed the effects of group (svPPA, lvPPA, nfvPPA, tAD or HCs), verb regularity (regular or irregular), verb frequency (HF or LF) and tense (present perfect or preterite). We carried out three separate regressions: the first GEE was conducted on the sum of all types of errors produced for both irregular and regular verbs and evaluated the effect of regularity in addition to the effect of group, frequency and tense; the other two GEEs considered only irregular verbs and evaluated the effect of group, frequency and tense separately for regularizations and for nonregularization errors.

ITEM	CORRECT ANSWER	REGULARIZATION ERROR	SEMIREGULARIZATION ERROR
Oggi prende [Today he/she takes]	-	-	-
Ieri ha ..... [Yesterday he/she has .....]	preso [taken]	prendetto [taked]	presetto [tooked]
Un anno fa ..... [One year ago he/she .....]	prese [took]	prendette [taked]	presette [tooked]

FIGURE 1 Example of an item and of regularization and semiregularization errors from the Italian verb inflection test (English translation between brackets).

The significance threshold was set at $p < .05$, corrected with Bonferroni adjustment for multiple comparisons, for post hoc contrasts.

RESULTS

Participants' general features

Patient groups were matched for age, sex, education, disease duration and MMSE score and were also matched with HCs for all demographic variables, with the exception of tAD patients who were significantly older than controls (Table 1).

Neuropsychological profiles are shown in Table 2. The tAD group was more impaired than the nfvPPA group on delayed recall of verbal and visuospatial material. LvPPA patients performed worse than tAD patients on the FAB and Letter fluency. The svPPA group was more impaired than the tAD group on Picture naming; than the lvPPA group on the PPT; and the nfvPPA group on both tests. NfvPPA patients performed worse than svPPA patients on forward Digit Span and worse than tAD patients on forward Digit Span and Letter fluency.

Analysis of errors on the verb inflection test

We did not include patients with nfvPPA in group analyses, since they showed severe difficulties in inflecting both irregular and regular verbs and only one of them was able to complete the task. He produced nine errors, all on LF verbs; only three were regularizations, all on preterite.

GEE analyses

Results of GEE on all inflection errors are reported in Table 3 (while group means for total errors and error subtypes for the two tenses and for low and high frequency verbs are shown in the Supplementary Table—Data S1). The adjusted quasi-likelihood under independence model criterion (QICC) testing the goodness of fit of the model was 1340.38. All main effects were significant: errors were more numerous on irregular than regular verbs, on LF than HF verbs, on preterite than on present perfect and in two patient groups: in svPPA compared with HCs (adjusted $p < .0001$) and tAD (adjusted $p = .002$) and in lvPPA compared with HCs (adjusted $p = .036$).

TABLE 1 Socio-demographic and clinical features of the five study groups.

	svPPA *n.* 10	lvPPA *n.* 11	nfvPPA *n.* 5	tAD *n.* 20	HCs *n.* 26	H^a/χ^2 (p)
Age	66.0 ± 11.1	72.3 ± 5.7	68.4 ± 6.3	74.7 ± 4.9*	65.0 ± 11.1	15.39 (.004)
Sex—*n.* (%) men	7 (70.0)	7 (63.6)	3 (60.0)	11 (55.0)	13 (50.0)	1.46 (.834)
Education (years)	12.6 ± 3.5	12.4 ± 1.6	13.6 ± 3.7	11.8 ± 3.5	13.4 ± 3.3	3.72 (.445)
Disease duration (years)	4.7 ± 2.2	3.8 ± 2.4	3.4 ± 1.9	3.4 ± 2.4	/	3.02 (.388)
MMSE	23.5 ± 4.8*	21.1 ± 4.5*	23.6 ± 3.6*	22.9 ± 3.2*	29.6 ± .8	35.73 (<.0001)

Note: Mean ± standard error.

Abbreviations: HCs, healthy controls; lvPPA, logopenic variant of primary progressive aphasia; MMSE, MiniMental state examination; nfvPPA, nonfluent variant of primary progressive aphasia; svPPA, semantic variant of primary progressive aphasia; tAD, typical Alzheimer's disease.

[a]Kruskall–Wallis test.

*Bonferroni-adjusted $p < .05$ versus HCs.

TABLE 2 Comparison of neuropsychological scores between patient groups.

	svPPA		lvPPA		nfvPPA		tAD		
Test (maximum score)	***n.***	***n.* 10**	***n.***	***n.* 11**	***n.***	***n.* 5**	***n.***	***n.* 20**	***H*[a] (*p*)**
Attentional matrices (60)	5[b]	34.2 ± 12.4	9	33.6 ± 9.9	5	33.8 ± 5.7	20	41.5 ± 11.4	3.62 (.305)
Forward digit span (9)	10	5.3 ± 1.2*	9	4.7 ± 1.3	5	3.6 ± .5	20	5.1 ± .9*	8.83 (.032)
Backward digit span (8)	10	3.9 ± .9	9	3.6 ± 1.1	5	2.8 ± .4	20	3.5 ± .9	6.04 (.110)
RAVLT									
Immediate recall (75)	9	23.7 ± 13.1	7	19.7 ± 5.2	5	21.0 ± 5.6	19	20.2 ± 6.8	.36 (.948)
Delayed recall (15)	9	4.4 ± 4.6	7	3.6 ± 2.5	5	3.6 ± 2.5	19	1.0 ± 1.7*	14.67 (.002)
ROCF—recall (36)	5[b]	10.0 ± 8.4	9	8.0 ± 4.2	5	11.6 ± 5.9	19	4.0 ± 3.4*	12.54 (.009)
ROCF—copy (36)	5[b]	31.4 ± 2.8	9	26.5 ± 8.0	5	28.0 ± 6.6	19	30.3 ± 3.5	1.25 (.742)
FAB (18)	7	13.5 ± 3.1	10	10.6 ± 3.3**	5	11.2 ± 3.6	20	14.8 ± 1.9	12.83 (.005)
Letter fluency	9	22.3 ± 8.9	10	16.2 ± 9.0**	5	8.4 ± 6.3	20	27.5 ± 8.5*	16.15 (.001)
Category fluency	9	24.3 ± 11.7	10	19.3 ± 7.5	5	24.0 ± 9.1	20	27.7 ± 9.1	4.73 (.192)
Picture naming (80)	9	40.7 ± 16.2*,**	9	58.1 ± 21.1	5	73.0 ± 6.2	18	70.0 ± 8.6	19.97 (<.0001)
PPT (52)	10	39.3 ± 4.4*	10	47.2 ± 4.1***	3	50.3 ± 2.9	/	n.a.	12.73 (.002)
AAT repetition (150)	5[b]	145.5 ± 5.1	9	120.6 ± 41.1	4	130.5 ± 16.0	/	n.a.	4.77 (.092)

Note: Mean ± standard deviation.

Abbreviations: AAT, Aachener Aphasie Test; FAB, Frontal Assessment Battery; HCs, healthy controls; lvPPA, logopenic variant of primary progressive aphasia; MMSE, MiniMental state examination; n.a., not administered; nfvPPA, nonfluent variant of primary progressive aphasia; PPT, pyramids and palm trees test; RAVLT, Rey auditory verbal learning test; ROCF, Rey-Osterrieth complex figure; svPPA, semantic variant of primary progressive aphasia; tAD, typical Alzheimer's disease.

[a]Kruskall–Wallis test.

[b]Five svPPA patients underwent a different neuropsychological battery that included heterogeneous measures of attention, visuocontructional abilities and repetition.

*Bonferroni-adjusted $p < .05$ versus nfvPPA. **Bonferroni-adjusted $p < .05$ versus tAD. ***Bonferroni-adjusted $p < .05$ versus svPPA.

TABLE 3 Model effects for all inflection errors and summary of results of post hoc analyses.

Source	Type III			Post hoc contrasts significant at Bonferroni-adjusted $p < .05$
	Wald χ^2	df	p	
(Intercept)	52.535	1	.000	/
Regularity	26.968	1	.000	More errors on irregular than regular verbs
Tense	44.561	1	.000	More errors on preterite than on present perfect
Frequency	88.156	1	.000	More errors on LF than HF verbs
Group	34.144	3	.000	More errors in svPPA than in HCs and tAD, and in lvPPA than in HCs
Regularity × Tense	.493	1	.483	–
Regularity × Frequency	21.193	1	.000	Disadvantage for irregular verbs was greater on LF than HF verbs
Regularity × Group	7.383	3	.061	–
Tense × Frequency	.162	1	.687	–
Tense × Group	20.123	3	.000	Disadvantage for preterite was greater in svPPA than in HCs
Frequency × Group	30.621	3	.000	Disadvantage for LF verbs was greater in svPPA than in tAD and in HCs
Regularity × Tense × Frequency	.057	1	.812	–
Regularity × Tense × Group	8.222	3	.042	No post hoc contrast survived Bonferroni correction
Regularity × Frequency × Group	6.077	3	.108	/
Tense × Frequency × Group	5.478	3	.140	–
Regularity × Tense × Frequency × Group	2.533	3	.469	–

Abbreviations: HCs, healthy controls; HF, high frequency; LF, low frequency; svPPA, semantic variant of primary progressive aphasia; tAD, typical Alzheimer's disease.

We also found statistically significant interactions between regularity and frequency, group and tense, and group and frequency: the disadvantage for irregular verbs was greater on LF than HF verbs (adjusted $p < .0001$); the disadvantage for preterite was greater in svPPA than in HCs (adjusted $p = .003$); the disadvantage for LF verbs was greater in svPPA than in tAD (adjusted $p = .005$) and in svPPA than in HCs (adjusted $p < .0001$).

Results of GEE on nonregularization errors are reported in the top section of Table 4. Adjusted QICC was 708.78. All main effects were significant. Nonregularization errors were more numerous on preterite than present perfect, on LF verbs than HF verbs and in two patient groups versus HCs, that is, svPPA (adjusted $p = .001$) and lvPPA (adjusted $p = .016$). Interaction between tense and group was also significant: the disadvantage for preterite was significantly greater in svPPA than in HCs (adjusted $p = .003$).

Results of GEE on regularizations are reported in the bottom section of Table 4. Adjusted QICC was 163.60. We found a significant main effect of frequency and group: regularizations were more numerous on LF verbs than HF verbs and in svPPA compared to lvPPA (adjusted $p < .0001$), tAD (adjusted $p < .0001$) and HCs (adjusted $p < .0001$). We also found a significant triple interaction between tense, frequency and group: the disadvantage for LF verbs was greater on present perfect and in svPPA compared with tAD (adjusted $p < .0001$) and HCs (adjusted $p < .0001$).

TABLE 4 Model effects for nonregularization errors on irregular verbs (top section) and regularizations (bottom section), and summary of results of post hoc analyses.

Source	Type III			Post hoc contrasts significant at Bonferroni-adjusted $p < .05$
	Wald χ^2	df	p	
Nonregularization errors				
(Intercept)	45.345	1	.000	/
Tense	24.619	1	.000	More errors on preterite than on present perfect
Frequency	47.286	1	.000	More errors on LF than HF verbs
Group	26.840	3	.000	More errors in svPPA and in lvPPA than in HCs
Tense × Frequency	.347	1	.556	–
Tense × Group	14.834	3	.002	Disadvantage for preterite was greater in svPPA than in HCs
Frequency × Group	10.550	3	.014	No post hoc contrast survived Bonferroni correction
Tense × Frequency × Group	.767	3	.857	–
Regularizations				
(Intercept)	62.229	1	.000	/
Tense	.295	1	.587	–
Frequency	18.555	1	.000	More errors on LF than HF verbs
Group	24.498	3	.000	More errors in svPPA than in all other groups
Tense × Frequency	1.317	1	.251	–
Tense × Group	5.537	3	.136	–
Frequency × Group	7.327	3	.062	–
Tense × Frequency × Group	7.976	3	.047	Disadvantage for LF verbs was greater on present perfect in svPPA than in tAD and in HCs

Abbreviations: HCs, healthy controls; HF, high frequency; LF, low frequency; lvPPA, logopenic variant of primary progressive aphasia; svPPA, semantic variant of primary progressive aphasia; tAD, typical Alzheimer's disease.

Comparison of ratio of regularizations

The ratio of regularization to nonregularization errors was not computed for five tAD patients, as they made zero nonregularization errors. For the same reason we did not include HCs in the analysis on ratio (over 70% of them made no (15/26) or only one (4/26) nonregularization error). The ratio was significantly higher in the svPPA group compared to both lvPPA [$H = 11.08$, adjusted $p = .039$] and tAD [$H = 10.72$, adjusted $p = .031$] (Figure 2).

ROC curve analysis showed that, at the Youden-based cutoff >.36, the ratio distinguished svPPA from tAD with 70.0% sensitivity and 80.0% specificity, and svPPA from lvPPA with 70.0% sensitivity and 81.8% specificity (Figure 3).

DISCUSSION

This study aimed to identify a neuropsychological marker of regularization that was sensitive to disruption of semantic memory in Italian svPPA patients. We used the same paradigm that had been successfully applied to a similarly transparent language, German, in a prior study by Billette et al. (2020). Those

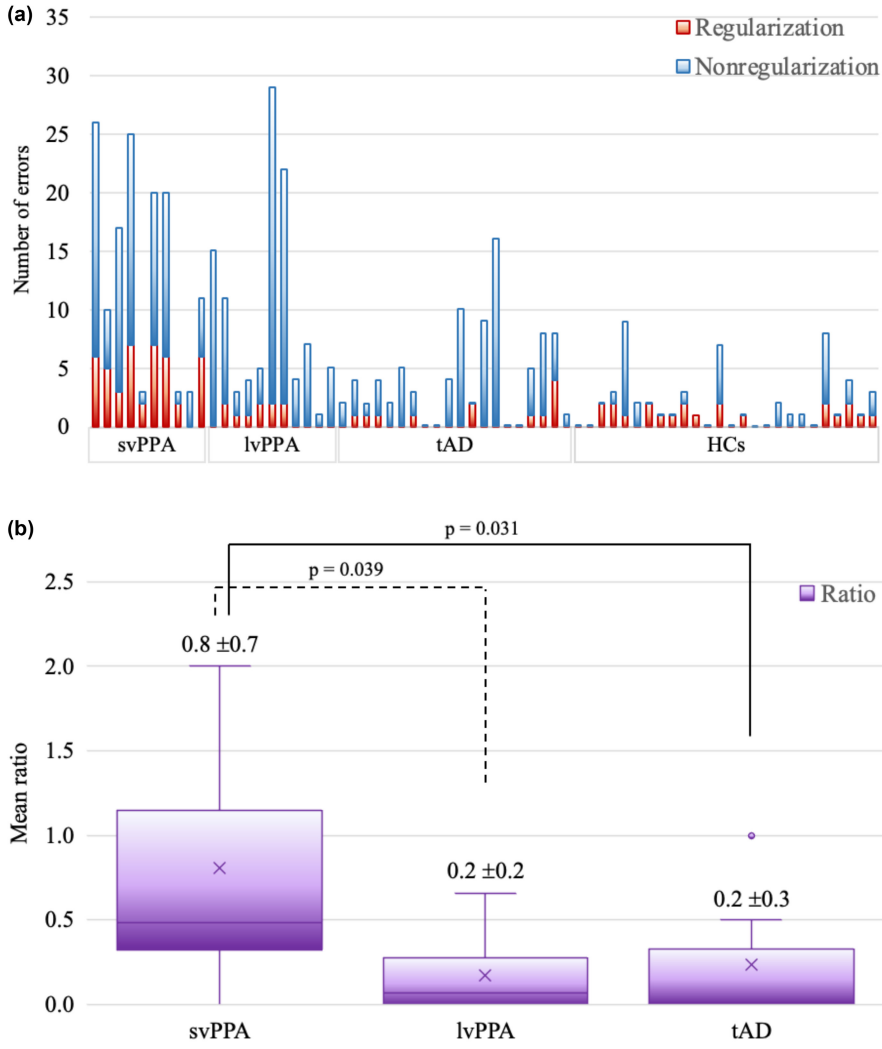

FIGURE 2 Distribution of errors in the study groups: (a) Frequency of regularization and nonregularization errors; (b) Comparison of ratios between regularizations and nonregularization errors (the higher the ratio the higher the number of regularizations than nonregularization errors). Ratios were not computed for HCs and for five tAD patients who did not make nonregularization errors. *p*-values are Bonferroni-adjusted. Values are presented as mean ± standard error. LvPPA, logopenic variant of primary progressive aphasia; svPPA, semantic variant of primary progressive aphasia; tAD, typical Alzheimer's disease.

authors demonstrated that svPPA patients showed a specific, major tendency to regularize irregular German verbs when inflecting into the perfect and preterite tenses, compared to patients with lvPPA or tAD. The present study confirmed that the same phenomenon could be demonstrated in Italian. Specifically, our main finding was that, while the prevalence of nonregularization errors when inflecting irregular verbs did not differ between svPPA, lvPPA and tAD (even if they were more prevalent in the two aphasic groups compared to HCs), regularization errors were significantly more numerous in svPPA than in all the other groups.

The utility of the IVIT was evident in the ROC analyses showing that compared to tAD and lvPPA, there was a sensitivity of 70% and specificity of ~80% for regularization errors to identify svPPA. Considering that regularization—in the form of surface dyslexia/dysgraphia—is only one out of six

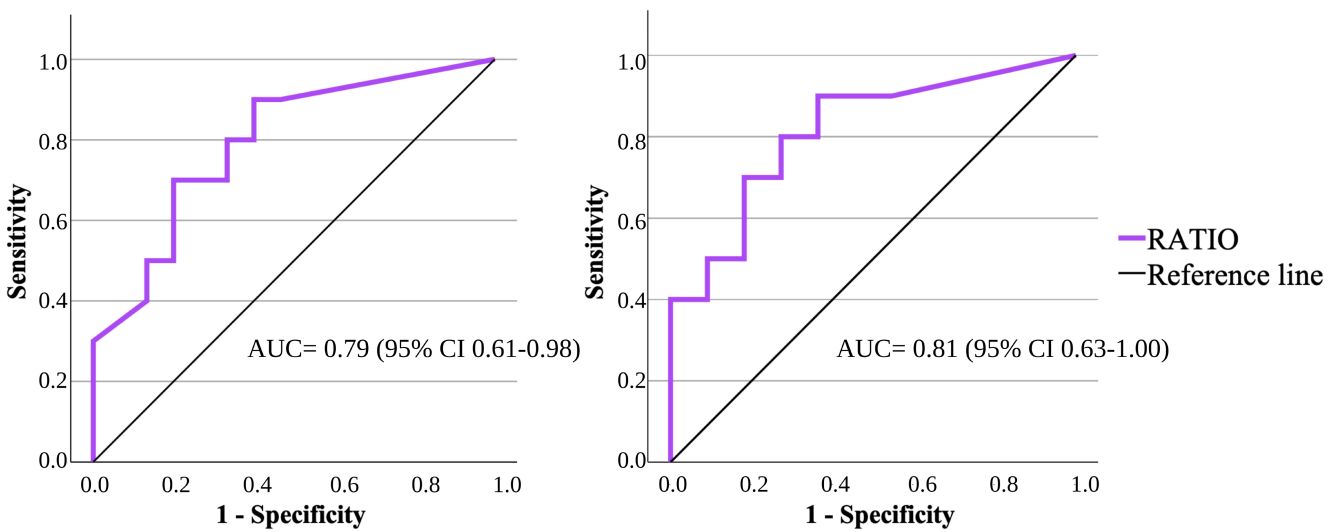

FIGURE 3 ROC curve analysis of ratio between regularizations and nonregularization errors for distinguishing svPPA from tAD (left) and lvPPA (right).

diagnostic features in the Gorno-Tempini et al. (2011) recommendations for diagnosing svPPA, it is particularly encouraging that this one test taken in isolation could have such good performance.

An ancillary prediction was that svPPA patients would show a disproportionate tendency to regularize LF verbs and the lower frequency, preterite, tense, due to the known influence of cumulative frequency. Results obtained from GEE on overall performance (combining all error types) on the IVIT indeed showed a significant main effect of both verb frequency and verb tense, that tended to be stronger for svPPA: poorer performance on LF than HF verbs and on preterite rather than present perfect was significantly more evident in this group relative to HCs and also relative to tAD for the verb frequency effect; lvPPA was somewhat intermediate and did not differ from any group. The main effects of frequency and tense were significant also in the analysis of nonregularization errors on irregular verbs, although the former was less specific for svPPA (the increase in the frequency of nonregularization errors from HF to LF verbs was comparable across groups).

When focusing specifically on regularization errors, however, the GEE analysis only confirmed a significant main effect of verb frequency, but not of tense; instead it highlighted an unexpected, significant interaction indicating a tendency for svPPA to regularize *present perfect more often than preterit*e, for LF verbs. Scrutiny of svPPA patients' individual performance on the IVIT revealed that those who regularized present perfect of LF verbs usually made nonregularization errors on preterite for the same items. While this observation ran contrary to our initial prediction, we propose that the explanation relates to the fact that while regularization is a manifestation of reliance on overlearned rules, there are instances where the rules may be so esoteric as to be more likely *unknown* than *overlearned*. For some Italian LF verbs producing preterite, it would appear to be so obscure that rules governing correct inflection are not well known to much of the population. Indeed, the preterite is typically used in written form and even some native Italian speakers may struggle with its correct usage. Consistent with this hypothesis, during the pilot phase of test development, the items that had to be discarded because >30% of HCs could not correctly inflect the verbs usually related to the preterite tense and even involved HF items in some instances.

Lack of knowledge of inflectional rules in the general population also raises the issue that poor performance on the IVIT may be confounded by low education levels. In the present study, all groups were matched for education level and less than 8 years of formal schooling was an exclusion criterion for study participation. In the German study (Billette et al., 2020), however, there was a trend that the tAD and lvPPA groups were less educated than the svPPA group; nonetheless, it was the svPPA group that made more regularization errors. This would suggest that while education may play a role in performance on a test of this type, its impact is likely to be negligible unless one were dealing with patients with an extreme lack of formal education. In this latter circumstance, it is likely that not just the IVIT but any formal testing of semantic memory would be impacted.

In addition to svPPA and lvPPA, we attempted to administer the IVIT to nfPPA patients. Of five patients in whom this was attempted, four could not do the test at all. This finding replicated the German study (Billette et al., 2020) that also reported the nfPPA patients are generally unable to inflect verbs almost certainly reflecting their known agrammatism.

CONCLUSION

Inflecting irregular verbs into past tenses offers a way to expose the regularization phenomenon in Italian that is a feature of degraded semantic knowledge. Testing irregular verb inflection in turn, therefore, offers a solution to the problem that Italian lacks the abundance of irregularly pronounced words that are found in English. As was reported previously in German, irregular verb inflection can be used as a substitute for the surface dyslexia/dysgraphia criterion in diagnosing svPPA in Italian speakers.

AUTHOR CONTRIBUTIONS

Daniele Licciardo: Validation; visualization; writing – original draft; software; methodology; formal analysis; data curation; investigation. **Valeria Isella:** Validation; visualization; writing – original draft;

project administration; methodology; formal analysis; data curation. **Elisa Canu:** Validation; visualization; writing – review and editing; supervision; data curation; investigation. **Marta Forestiero:** Validation; visualization; data curation; investigation. **Veronica Castelnovo:** Validation; visualization; data curation; investigation. **Stefania Valsecchi:** Validation; visualization; data curation; investigation. **Federica Agosta:** Validation; visualization; writing – review and editing; supervision; funding acquisition. **Massimo Filippi:** Validation; visualization; writing – review and editing; funding acquisition. **Ildebrando Appollonio:** Validation; visualization; writing – review and editing; supervision. **Peter J Nestor:** Conceptualization; writing – original draft; supervision; writing – review and editing; methodology.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Data S1: Supporting Information.

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