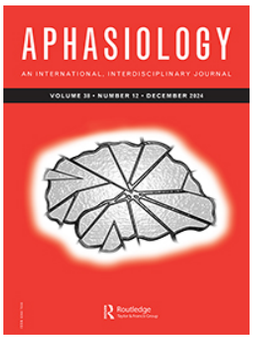

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Teasing apart time reference-related encoding and retrieval deficits in aphasia: evidence from Greek, Russian, Italian and English

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ABSTRACT

Background: Persons with aphasia (PWAs) are often impaired in time reference/tense production. It has been suggested that this impairment is due to encoding or/and retrieval deficits. However, to the best of our knowledge, no experimental design that enables teasing apart selective encoding and retrieval deficits has been proposed thus far.

Aims: This study aims at disentangling time reference-related encoding deficits from time reference-related retrieval deficits in PWAs.

Methods & procedures: Two sentence completion tasks tapping production of time reference and subject-verb agreement (control condition) were administered to eight Greek-speaking PWAs, eight Russian-speaking PWAs, six Italian-speaking PWAs, seven English-speaking PWAs and four groups of language-, age- and education-matched healthy controls. Task 1 tapped encoding and retrieval processes to a similar extent. Task 2 predominantly tapped retrieval processes. Comparisons between each PWA and the corresponding control group, as well as within-participant comparisons were performed.

Outcomes & results: All four control groups performed at ceiling. Twenty-eight out of 29 PWAs were impaired in time reference in at least one of the two completion tasks, and all but three PWAs were impaired in production of subject-verb agreement in at least one of the two tasks. In all language groups, there were PWAs exhibiting between-task dissociations. A double dissociation emerged in the time reference condition, as some Greek-, Russian- and English-speaking PWAs performed better on Task 1 than on Task 2, whereas other Greek- and Italian-speaking PWAs performed worse on Task 1

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than on Task 2. In the agreement condition, in each language group, there were PWAs performing better on Task 1 than on Task 2. However, none PWA exhibited the opposite pattern. Based on the results, we identified both PWAs with selective time reference-related encoding deficits and PWAs with selective time reference-related retrieval deficits.
Conclusions: The present experimental design provides a sound basis for teasing apart selective time reference-related encoding deficits and time reference-related retrieval deficits.

Introduction

A thorough, reliable and valid neuropsychological assessment can inform the clinician about the linguistic and cognitive strengths and weaknesses of individuals with language disorders, which in turn can inform treatment programs tailored to the specific needs of each client (Varkanitsa et al., 2023). We consider psycholinguistic assessment to be part of neuropsychological assessment. In this study, we focus on verb-related morphosyntactic/morphosemantic assessment. Specifically, we focus on production of time reference (TR)/tense, which is often impaired in persons with stroke-induced aphasia (PWAs) (e.g., Faroqi-Shah & Thompson, 2007; Friedmann & Grodzinsky, 1997; Fyndanis, Arcara, Christidou & Caplan, 2018; Gavarró & Martínez-Ferreiro, 2007; Kok et al., 2007; Wenzlaff & Clahsen, 2004). The current study has been largely inspired by the work of Faroqi-Shah and Thompson (2007), in which English-speaking participants with agrammatic aphasia were administered sentence completion tasks tapping verb production and utilizing a multiple choice format (e.g., *The man will* _____ *the Canadian border* [response options: cross, crosses, crossing]; *Yesterday Rob* _____ *at the meeting* [response options: speaks, spoke, speak]; *Tomorrow John* _____ *a question* [response options: will ask, was asking, is asked]; *Nowadays I* _____ *a mile* [response options: was jogging, jog, will jog]). The most frequent error type was mismatches between the temporal adverb and the selected verb form (e.g., **Yesterday Mary speaks to the President*).[1] The authors attributed participants' difficulty in producing inflected verbs to tense-related encoding and/or retrieval deficits. Encoding and retrieval are two major components of the TR process (see, among others, Bock & Levelt, 2002; Levelt, 1999). For instance, to express an event that occurred before the utterance time, speakers must encode the abstract past feature of the verb and subsequently retrieve its corresponding phonological form. Interestingly, as mentioned in Faroqi-Shah and Thompson (2007), in another study on English agrammatic aphasia (Faroqi-Shah, 2006), participants with aphasia were not impaired in the selection of the temporal adverb when a finite verb form was provided (e.g., *The tourist from France ate pizza* _____ [response options: every day, yesterday, next week]). These participants were only impaired in the selection of the verb form when a temporal context was provided (e.g., *After Mary moved the sofa, she* _____ *her back* [response options: sprained, sprains, will sprain]). This pattern was interpreted as suggesting that individuals with agrammatic aphasia have a tense-related retrieval deficit (specifically, difficulty retrieving tensed verb forms) rather than a tense-related encoding deficit (Faroqi-Shah & Thompson, 2007). One could argue, however, that completion tasks providing response options are similar to contrastive

sentence grammaticality judgment tasks. The conclusions based on such tasks, therefore, might not hold for production. In fact, it seems that the sentence completion tasks used in Faroqi-Shah and Thompson's (2007) and Faroqi-Shah's (2006) studies required decoding, not encoding, of tense features and judgment of the compatibility between the temporal adverbial (or the temporal clause) and the verb form. Therefore, it is not yet clear whether impaired TR production in PWAs is due to TR-related encoding deficits or due to TR-related retrieval deficits (or due to both). Some PWAs may predominantly have encoding deficits, and others may predominantly have retrieval deficits. Some other PWAs may have encoding and retrieval deficits to a similar extent.

Additionally, in some PWAs, TR-related encoding and/or retrieval deficits may differentially impact reference to different time frames. This possibility aligns with evidence that PWAs often exhibit dissociations between past and non-past reference (e.g., Bastiaanse et al., 2011; Fyndanis, Arcara, Capasso, et al., 2018; Nerantzini et al., 2020). This seems to be the case in both nonfluent and fluent aphasia (Fyndanis, Arcara, Capasso, et al., 2018). In several studies on TR in different languages, Bastiaanse and colleagues (e.g., Bastiaanse, 2008; Bastiaanse et al., 2011; Dragoy & Bastiaanse, 2013; Martínez-Ferreiro & Bastiaanse, 2013; Yarbay Duman & Bastiaanse, 2009) found that, in aphasia, reference to the past is more prone to impairment than reference to the present or future. Further evidence for this pattern has been provided by a recent meta-analysis by Cordonier et al. (2024). To account for this pattern, Bastiaanse et al. (2011) proposed the PAst DIscourse LInking Hypothesis (PADILIH), which states that reference to the past is more demanding than reference to the non-past (i.e., present and/or future) because it involves discourse linking (Zagona, 2003, 2013). However, not all aphasia studies on TR provided empirical evidence for the PADILIH. For example, some studies on Greek aphasia that tested production of TR with sentence completion tasks found no difference between past and future reference at the group level (e.g., Fyndanis, Arcara, Capasso, et al., 2018; Koukoulioti & Bastiaanse, 2020; Nerantzini et al., 2020). This divergent outcome challenges the generalizability of the PADILIH to all language populations. Interestingly, Fyndanis, Arcara, Capasso, et al. (2018) reported a double dissociation between past and future reference in their Greek-speaking PWAs, as some participants performed better on the production of past reference than on the production of future reference, and others exhibited the opposite pattern. The authors interpreted this double dissociation as suggesting that different sources of difficulty differentially affect the ability of PWAs to refer to the past or to the future. Such sources may include the semantic components of TR,[2] language-specific morphological means of expressing past and future reference, PWAs' selective deficits in TR-related encoding or retrieval processes, and others. The authors also noted that the bulk of the supporting evidence for the PADILIH (Bastiaanse et al., 2011) has been provided by studies employing the Test for Assessing Reference of Time (TART) (Bastiaanse et al., 2008), which is a task that predominantly investigates the participant's ability to retrieve the verb form that corresponds to a given time frame.[3] In contrast, the transformational sentence completion task used in Fyndanis, Arcara, Capasso, et al. (2018) tapped encoding and retrieval to a similar extent. (For information about transformational sentence completion tasks, see the Methods section.) Fyndanis, Arcara, Capasso, et al. (2018) contended that the conflicting outcomes in their investigation and in studies utilizing the TART (e.g., Bastiaanse, 2008; Bastiaanse et al., 2011, Dragoy & Bastiaanse, 2013; Koukoulioti & Bastiaanse, 2020) could potentially be harmonized by

postulating that during the retrieval phase, referring to the past may be more demanding in terms of processing resources than referring to the future and, conversely, in the encoding phase, referring to the future may be more challenging than referring to the past. If these two fundamental processes associated with TR exhibit opposing patterns of selective difficulty, and assuming that certain PWAs encounter issues solely in encoding or retrieval, while others face mixed challenges, the contrasting dissociations between past and future reference might cancel each other at the group level. Substantiation for this hypothesis would manifest by discovering that participants with a selective retrieval deficit exhibit greater impairment in past reference than in future reference, while participants with a selective encoding deficit display more pronounced difficulties in future reference than in past reference.

As Fyndanis, Arcara, Capasso, et al. (2018) noted, the above hypothesis enables reconciling their results with the findings of most studies that used the TART (Bastiaanse, 2008). This was "an ad hoc hypothesis, driven by behavioural observations more than by theoretical motivations. Its evaluation will need an explicit theoretical framework providing principled reasons why past reference should be more taxing on retrieval and future reference on encoding processes [. . .]" (Fyndanis, Arcara, Capasso, et al., 2018, p. 838). One could assume that encoding future reference might be more challenging because reference to the future involves projections to possible worlds, which is a more abstract operation than referring to an event that has already taken place; and retrieval of past-referring verb forms might be harder than retrieval of future-referring verb forms if, in a given laguage, past-referring verb forms are morphologically more complex compared to future-referring verb forms. Given the cross-linguistic differences in the way past vs. future reference are morphologically expressed (see Table 1 in the current study), the "retrieval component" of this hypothesis is not expected to have cross-linguistic validity.

Table 1. Past and future reference in Greek, Russian, Italian and English (for the 1st person, singular number, indicative mood of the verb *κλείνω*, *zakryvat'*, *chiudere*, *close* "close").

	Greek	Russian	Italian	English
Past Reference	έκλεισα ['eklisa] (έκλεινα ['eklina])	zakryval [zəkrɨ'val] (zakryl [zɐ'krɨl])	ho chiuso [o kj'u:zo] (chiudevo [kjʊd'ɛ:vo]/ chiusi [kj'u:zi])	closed (was closing)
Future Reference	θα κλείσω [θa kl'iso] (θα κλείνω [θa kl'ino])	budet zakryvat' [budʲ ɪt zəkrɨ'vatʲ] (zakroet [zɐ'krojɪt]/ zakryvayu [zəkrɨ'vajʉ])	chiuderó [kjʊder'o] (chiudo [kj'u:do])	will close (am closing/will be closing/will be closed)

The present tense in Italian and Russian (e.g., *chiudo* [kj'u:do] and *zakryvayu* [zəkrɨ'vajʉ], respectively), and the present continuous in English (e.g., (I) *am closing*), are often used to refer to the future in the presence of a future-referring temporal adverbial. In Greek, the difference between the verb forms *έκλεισα* ['eklisa] and *έκλεινα* ['eklina], and between *θα κλείσω* [θa kl'iso] and *θα κλείνω* [θa kl'ino] reflects the opposition between perfective and imperfective aspect, respectively. Likewise, the Italian verb forms *ho chiuso* [o kj'u:zo] / *chiusi* [kj'u:zi] and *chiudevo* [kjʊd'ɛ:vo], and the English verb forms *closed* and *was closing* encode perfective and imperfective aspect, respectively. In Russian, imperfective (*zakryvat'* [zəkrɨ'vatʲ]) and perfective (*zakryt'* [zɐ'krɨtʲ]) verbs have different paradigms. In the past tense, both of them have monolectic forms (*zakryval* [zəkrɨ'val] / *zakryl* [zɐ'krɨl]). Future reference can be expressed via periphrastic verb forms (*budet zakryvat'* [budʲɪt zəkrɨ'vatʲ]), which encode imperfective aspect, or monolectic verb forms (*zakroet* [zɐ'krojɪt]), which encode perfective aspect. In English future reference, the modal auxiliary *will* can convey either a perfective or imperfective reading depending on context and verb properties (Comrie, 1976). Constructions such as *will be closing* either encode progressive aspect or are underspecified for aspect (Celle & Smith, 2010). The future-referring passive constructions *will be* + *participle* (e.g., *will be closed*) can convey a prospective action/event without further aspectual specification.

Lastly, Fyndanis, Arcara, Capasso, et al. (2018) proposed that, to disentangle selective TR-related encoding deficits from selective TR-related retrieval deficits, an experimental design should encompass a transformational sentence completion task and a task akin to the TART (Bastiaanse, 2008). Given that the transformational sentence completion task engages both encoding and retrieval processes to a comparable degree, while the TART primarily focuses on retrieval processes, individuals with selective encoding difficulties should exhibit better performance on the TART compared to the transformational sentence completion task. Conversely, participants experiencing a selective deficit in retrieval processes should demonstrate similarly impaired performance across both tasks.

Following up on Faroqi-Shah and Thompson's (2007) and Fyndanis, Arcara, Capasso, et al.'s (2018) studies, the present study aims at teasing apart TR-related encoding processes and TR-related retrieval processes, identifying selective TR-related encoding or/and retrieval deficits in PWAs. Relatedly, it addresses whether there are task effects when exploring TR production with constrained tasks. Moreover, the study tests Fyndanis, Arcara, Capasso, et al.'s (2018) hypothesis that PWAs with selective TR-related retrieval deficits might be more impaired in past reference than in future reference, and PWAs with selective TR-related encoding deficits might be more impaired in future reference than in past reference.

Background on time reference in Greek, Russian, Italian and English

In all four languages, TR is made through verb inflection and temporal adverbials. As shown in Table 1, reference to the past (for both perfective and imperfective verbs) through verb inflection is predominantly expressed by monolectic verb forms in Greek and Russian, and by both monolectic and periphrastic verb forms in English and spoken Italian in Northern Italy, which is relevant here. On the other hand, reference to the future is predominantly made via monolectic verb forms in Italian, and via periphrastic verb forms in Greek (where a finite nonpast verb form is preceded by the particle *θa*) and English (where a nonpast verb form is preceded by the modal verb *will*). In Russian, both monolectic and periphrastic forms referring to the future are possible: future-referring monolectic verb forms encode perfective aspect, whereas future-referring periphrastic verb forms encode imperfective aspect. The latter forms consist of the auxiliary verb *быть* "*to be*" in the future tense and the infinitival form of a verb (with the former preceding the latter).

Methods

Participants

Eight Greek-speaking PWAs (four female, M_{age} = 63.5 years, SD = 7.3, range 51–76 years; M number of years of formal education = 11.6, SD = 5.4, range 2–19), eight Russian-speaking PWAs (seven female; M_{age} = 57.6 years, SD = 9.6, range 45–74 years; M number of years of formal education = 14, SD = 2.2, range 11–18), six Italian-speaking PWAs (all male, M_{age} = 54.8, SD = 4.1, range 48–60 years; M number of years of formal education = 11.5, SD = 2.7, range 8–14), seven English-speaking PWAs (two female, M_{age} = 57.4 years, SD = 12.0, range 35–71 years; M number of years of formal education = 14.7, SD = 2.9,

range 12–20) and four groups of language-, age- and education-matched healthy controls participated in the study.

Both persons with non-fluent aphasia and persons with fluent aphasia took part in the study. In all PWAs, aphasia resulted from a single left-hemisphere stroke. As reported by speech/language therapists (SLTs), all PWAs had sufficient auditory comprehension abilities, and no or mild motor speech disorders such as dysarthria and speech apraxia. SLTs' reports were based on PWAs' performance on aphasia assessment tests (for Greek: Boston Diagnostic Aphasia Examination-Short Form [BDAE-SF; Goodglass et al., 2001; Messinis et al., 2013]; for Italian: Aachen Aphasia Test [AAT; Luzzatti et al., 1996]; for English: Western Aphasia Battery-Revised [WAB-R; Kertesz, 2007]; for Russian: scale for assessing the severity of speech and language disorders in individuals with local brain damage [Vasserman et al., 1997]). Additionally, for Italian, SLTs' reports were based on PWAs' performance on an Italian version of the Robertson scale (Fussi & Cantagallo, 1997), which was administered only to participants who showed signs of dysarthria when completing the AAT. Furthermore, all participants presented with (corrected to) normal hearing and vision (see note in Table 5 about EP7), and none of them had a history of (premorbid) neurological or psychiatric disorders, traumatic brain injuries or alcohol/drug abuse.

All eight Greek-speaking PWAs were diagnosed with chronic aphasia (*M* time post-onset = 41.3 months, *SD* = 13.4, range = 17–62 months). Based on the published Greek standardized version of the BDAE-SF (Goodglass et al., 2001; Greek version by; Messinis et al., 2013), five participants were diagnosed with non-fluent aphasia (three participants with Broca's aphasia and one with transcortical motor aphasia) and three with fluent aphasia. The severity classification of the Greek-speaking PWAs was determined using the BDAE-SF. All participants were recruited by a Greek-speaking SLT who had previously provided their therapy. Testing was conducted in the participants' homes (in Thessaloniki, Greece). Table 2 summarizes the available demographic and clinical information about the Greek-speaking participants.

Of the eight Russian-speaking PWAs, six were diagnosed with chronic aphasia (post-onset range: 39–110 months) and two with subacute aphasia (post-onset range: 3–4 months). For the entire group of Russian-speaking PWAs, the mean time post-onset was 55.4 months (*SD* = 39.4, range = 3–110 months). They were selected according to their medical reports in the Center for Speech Pathology and Neurorehabilitation (Moscow, Russia). Prior to their inclusion in the study, a professional SLT examined all Russian-speaking PWAs with the scale for assessing the severity of speech and language disorders in individuals with local brain damage (Vasserman et al., 1997). Severity of aphasia was scaled from 0 to 7 where 0 indicates absence of deficit, and 7 corresponds to a very severe impairment ($M_{severity}$ = 4.25, *SD* = 0.89, range = 3–6). Aphasia types were defined according to Luria's aphasia classification (for review, see Akhutina, 2016). Only individuals diagnosed with the primary non-fluent aphasia types (i.e., efferent motor, complex motor or dynamic aphasia) participated in the study. Russian-speaking participants' detailed clinical and demographic information is presented in Table 3.

The mean time post stroke for the Italian-speaking PWAs was 37.5 months (SD = 22.5; range = 13–61 months). Aphasia type was determined by a clinical assessment made by an expert SLT using the AAT (Luzzatti et al., 1996). Four patients were diagnosed with Broca's aphasia (following a left ischemic lesion [*N* = 2] or a left

Table 2. Greek-speaking PWAs' and control participants' background information.

	GP1	GP2	GP3	GP4	GP5	GP6	GP7	GP8	Group of PWAs (*N* = 8) (Mean (SD))	Control group (*N* = 8) (Mean (SD))
Sex	M	M	F	F	F	F	M	M	4F, 4 M	6F, 2 M
Age (years)	67	57	64	65	66	76	62	51	63.5 (7.3)	63.8 (6.9)
Education (years)	14	11	16	13	6	2	19	12	11.6 (5.4)	12.2 (4.2)
Handedness	R	L	R	R	R	R	L	R	6 R, 2 L	7 R, 1 L
Etiology	L CVA	L CVA	L CVA	L CVA	L CVA	L CVA	L CVA	L CVA	n.a.	n.a.
Aphasia post-onset (months)	62	45	45	44	42	17	28	47	41.3 (13.4)	n.a.
Other conditions	Right hemiparesis	Right hemiparesis	Right hemiplegia	Very mild right hemiparesis	n.a.	Mild right hemiparesis	No	Right hemiplegia	n.a.	No
Hearing & Vision	Normal or corrected to normal	Normal or corrected to normal	Normal or corrected to normal	Normal or corrected to normal	Normal or corrected to normal	Normal or corrected to normal	Normal or corrected to normal	Normal or corrected to normal	n.a.	Normal or corrected to normal
Diagnosis	Nonfluent aphasia (Broca's aphasia)	Nonfluent aphasia (Broca's aphasia)	Nonfluent aphasia (Transcortical motor aphasia)	Nonfluent aphasia (Broca's aphasia)	Nonfluent aphasia (unclassifiable)	Fluent aphasia (unclassifiable)	Fluent aphasia (unclassifiable)	Fluent aphasia (unclassifiable)	5 nonfluent aphasia, 3 fluent aphasia	n.a.
Lesion site	Not available	Not available	Not available	Not available	Not available	Parietal lobe	Not available	Not available	n.a.	n.a.
Severity of aphasia	Moderate-Severe	Mild-Moderate	Moderate-Severe	Moderate-Severe	Mild	Severe	Severe	Moderate-Severe	n.a.	n.a.

GP = Greek-speaking participant with aphasia; SD = Standard Deviation; M = Male; F = Female; CVA = Cerebrovascular Accident; n.a. = not applicable; R = Right; L = Left.

Table 3. Russian-speaking PWAs' and control participants' background information.

	RP1	RP2	RP3	RP4	RP5	RP6	RP7	RP8	Group of PWAs ($N = 8$) (Mean (SD))	Control group ($N = 11$) (Mean (SD))
Sex	M	F	F	F	F	F	F	F	7F, 1 M	3 M, 8F
Age (years)	57	47	64	61	45	52	74	61	57.6(9.6)	58.2(8.9)
Education (years)	11	12	13	15	15	13	15	18	14(2.2)	15.8(3.0)
Handedness	R	R	R	R	R	R	R	R	All R	All R
Etiology	Left ischemic CVA	Left ischemic CVA	Left ischemic CVA	Left ischemic CVA	Left hemorrhagic CVA	Left ischemic CVA	Left ischemic CVA	Left ischemic CVA	n.a.	n.a.
Aphasia post-onset (months)	110	39	4	82	43	3	77	85	55.4(39.4)	n.a.
Other conditions	Moderate right hemiparesis	Right-sided hemihypesthesia	No	Mild right hemiparesis	Severe right hemiparesis	Right hemiparesis	No	No	n.a.	n.a.
Hearing/ Vision	Normal/ Corrected to normal	Normal/ Corrected to normal	Normal/ Corrected to normal	Normal/ Corrected to normal	Normal/ Corrected to normal	Normal/ Corrected to normal	Normal/ Corrected to normal	Normal/ Corrected to normal	Normal/Normal or corrected to normal	Normal or corrected to normal
Diagnosis	Efferent motor aphasia; mild dysarthria	Complex motor aphasia and dynamic aphasia	Efferent motor aphasia	Complex motor aphasia	Complex motor aphasia	Complex motor aphasia	Complex motor aphasia; mild dysarthria	Efferent motor aphasia with elements of sensory aphasia	n.a.	n.a.
Lesion site	Left fronto- temporal regions and the basal ganglia	Left fronto-temporal regions (IFG, STG, insula)	Left frontal, cortical and subcortical	Left fronto-temporo-parietal	Left insula and basal ganglia	Left frontal and parietal regions	Left fronto-temporo-parietal	Left fronto-temporo-parietal	n.a.	n.a.
Severity of aphasia	Mild-Moderate	Moderate-Severe	Moderate	Moderate	Moderate	Moderate	Severe	Moderate	n.a.	n.a.

RP = Russian-speaking participant with aphasia; SD = Standard Deviation; M = Male; F = Female; CVA = Cerebrovascular Accident; n.a. = not applicable; R = Right; L = Left.

hemorrhagic lesion [$N = 2$]), and two with mixed transcortical aphasia (following a left hemorrhagic lesion). The severity classification of the Italian-speaking PWAs was based on the AAT (Luzzatti et al., 1996).

Four PWAs were outpatients, and two PWAs were still inpatients in the neurorehabilitation ward at the time of testing. All Italian-speaking PWAs were recruited and tested at the San Camillo Rehabilitation Hospital in Lido/Venice, Italy. The background information for the Italian-speaking participants is presented in Table 4.

The American English-speaking PWAs were recruited from existing participant databases in the Center for Brain Recovery at Boston University. All PWAs were diagnosed with chronic aphasia (*M* time post-onset = 96.3 months, *SD* = 51.6, range = 24–162 months) by SLTs. The WAB-R (Kertesz, 2007) was used to quantify severity and classify aphasia subtype. Based on the WAB-R, six participants were diagnosed with fluent profiles of aphasia and one with a non-fluent profile. Detailed clinical and demographic information is available in Table 5.

The different methods of aphasia assessment and the different classification systems used here largely reflect the fact that, at the time of testing, there were no standardized and normed Greek, Italian, Russian and English versions of the *same* diagnostic aphasia battery/test available.

In Thessaloniki, Lido/Venice and Moscow, healthy control participants were recruited by contacting the examiners' friends and relatives and patients' family members, as well as through adverts. In Boston, healthy controls were recruited from existing participant databases in the Center for Brain Recovery at Boston University. All healthy controls older than 60 years were administered the Montreal Cognitive Assessment to exclude participants with signs of dementia (English version: Nasreddine et al., 2005; Greek version: Poptsi et al., 2019; Russian version: Freud et al., 2020; Italian version: Santangelo et al., 2015).

The data reported here are part of an ongoing project on aphasia (*Machine Learning Aphasia*) that involves testing Greek-, Russian-, Italian, English- and Norwegian-speaking individuals with stroke-induced aphasia. Norwegian data were not reported as we have only tested three Norwegian-speaking PWAs thus far. We reported data from the other languages, however, to have a large enough pool of PWAs who are impaired in TR production. The rationale was that increasing the sample size makes it more likely to detect PWAs with selective TR-related encoding deficits and PWAs with selective TR-related retrieval deficits.

The study was approved by the Norwegian Centre for Research Data (Notification Form 657,769), the Cyprus National Bioethics Committee (protocol reference number ΕΕΒΚ/ΕΠ/2021/47), the HSE Committee on Interuniversity Surveys and Ethical Assessment of Empirical Research (protocol #72, 10.10.2020) (Moscow, Russia), the Ethics Committee for clinical experimentation of Venice and IRCCS San Camillo Hospital (reference number 1290/IRCCS San Camillo) (Venice, Italy), and the Institutional Review Board for the Charles River Campus at Boston University (IRB, protocol reference number 3309E) (Boston, USA). All participants took part in the study on a voluntary basis and gave informed consent in accordance with the Declaration of Helsinki.

Table 4. Italian-speaking PWAs' and control participants' background information.

	IP1	IP2	IP3	IP4	IP5	IP6	Group of PWAs (Mean (SD))	Control group ($N = 7$) (Mean (SD))
Sex	M	M	M	M	M	M	6 M	4F, 3 M
Age (years)	53	56	60	48	55	57	54.8(4.1)	59.0(4.6)
Education (years)	8	13	13	8	13	14	11.5(2.7)	14.4(2.3)
Handedness	R	R	R	R	R	R	All R	All R
Etiology	Left ischemic CVA	Left hemorrhagic CVA	Left hemorrhagic CVA	Left hemorrhagic CVA	Left hemorrhagic CVA	Left ischemic CVA	n.a.	n.a.
Aphasia post-onset (months)	13	15	24	61	54	58	37.5(22.5)	n.a.
Other conditions	Mild right hemiparesis	Right hemiplegia	Very mild right hemiparesis	Mild right hemiparesis	Right hemiplegia	Mild right upper hemiparesis	n.a.	No
Hearing/ Vision	Normal/Normal	Normal/ Normal	Normal/ Corrected to normal	Normal/ Corrected to normal	Corrected to normal/ Corrected to normal	Normal/Normal	Normal or corrected to normal	Normal or corrected to normal
Diagnosis	Broca's aphasia	Broca's aphasia	Mixed transcortical aphasia	Mixed transcortical aphasia	Broca's aphasia	Broca's aphasia	n.a.	n.a.
Lesion site	Left fronto-parietal-insular cortico-subcortical regions	Left fronto-temporal cortex	Left fronto-temporo-parietal cortex	Left temporal cortex; left capsular and semioval nuclei	Left parieto-temporal cortical and subcortical regions	Left fronto-temporo-parietal cortical and subortical regions	n.a.	n.a.
Severity of aphasia	Moderate-Severe	Moderate-Severe	Mild-Moderate	Mild-Moderate	Moderate	Moderate	n.a.	n.a.

IP = Italian-speaking participant with aphasia; SD = Standard Deviation; M = Male; F = Female;
CVA = Cerebrovascular Accident; n.a. = not applicable; R = Right; L = Left.

Table 5. English-speaking PWAs' and control participants' background information.

	EP1	EP2	EP3	EP4	EP5	EP6	EP7	Group of PWAs ($N = 7$) (Mean (SD))	Control group ($N = 7$) (Mean (SD))
Sex	M	M	F	M	M	F	M	2F, 5 M	5F, 2 M
Age (years)	59	71	56	68	62	51	35	57.4(12.0)	64.0 (8.3)
Education (years)	12	13	17	12	14	20	15	14.7(2.9)	18(2.8)
Handedness	R	L	R	R	R	L	R	5 R, 2 L	All R
Etiology	Left ischemic CVA	Left ischemic CVA	Left ischemic CVA	Left ischemic CVA	Left ischemic CVA	Left ischemic CVA	Left hemorrhagic CVA	n.a.	n.a.
Aphasia post-onset (months)	161	92	69	59	107	24	162	96.3(51.6)	n.a.
Other conditions	Right hemiplegia	Right-sided weakness	Right hemiparesis	Right-sided weakness	Right hemiparesis	Right hemiparesis	Right hemiparesis; hemianopsia*	n.a.	n.a.
Hearing & Vision	Normal/ Corrected to Normal	Normal/ Normal	Normal/ Normal	Normal/ Corrected to Normal	Corrected to Normal/ Corrected to Normal	Normal/ Normal	Normal/ Impaired*	n.a.	n.a.
Diagnosis	Anomic aphasia	Anomic aphasia; dysarthria	Transcortical sensory aphasia	Anomic aphasia; apraxia	Broca's aphasia; dysarthria	Anomic aphasia	Anomic aphasia	6 fluent aphasia, 1 nonfluent aphasia	n.a.
Lesion site	Left anterior temporal and inferior frontal	Left temporal regions and basal ganglia	Left middle cerebral artery territory	Left periventricular white matter and basal ganglia	Left parietal and superior temporal lobes, insular cortex, and caudate nucleus	Left frontal lobe, insula, and basal ganglia	Left sylvian fissure	n.a.	n.a.
Severity of aphasia	Mild	Mild	Mild-Moderate	Mild-Moderate	Moderate	Mild	Mild	n.a.	n.a.

EP = English-speaking participant with aphasia; SD = Standard Deviation; M = Male; F = Female; CVA = Cerebrovascular Accident; n.a. = not applicable; R = Right; L = Left.
*EP7 compensated for hemianopsia (25–50% reduction of inner visual field in each eye) throughout testing by turning head and fixating written stimuli with ease.

Experimental design

We developed two tasks tapping TR and subject-verb Agreement production. Task 1 was a transformational sentence completion task tapping encoding and retrieval processes to a similar extent, and Task 2 was a non-transformational sentence completion task predominantly tapping retrieval processes (see next and Tables 6 and 7). In the TR condition, both tasks tapped into production of past reference and future reference. Reference to the present was not tested because, as noted by Fyndanis, Arcara, Capasso, et al. (2018, p. 832) "temporal adverbials prototypically associated with present reference, such as *now* and *today*, commonly used to elicit present-tensed/present reference verbs, are also compatible with future-tensed/future reference verbs (e.g., *Now I will play guitar*), making it hard to reliably test reference to the present (Fyndanis et al., 2012). Moreover, present tense likely acts as the default ('unmarked') tense value, which might be due to

Table 6. Examples of the past reference (sub)condition of the Greek, Russian, Italian and English versions of the transformational sentence completion task (Task 1) and the non-transformational sentence completion task (Task 2).

Task 1	Past Reference
Source Sentence	GR: Οι κηπουροί αύριο θα ποτίσουν τα λουλούδια. [i cipur'i 'avrio θa pot'isun ta lul'uðja] "The gardeners tomorrow will water the flowers (lit.)" RU: Садовник завтра польет растения [sɐ'dovnʲ ɪk 'zaftrə pɐlʲ'jət rɐ'sʲtʲenʲ ɪjə] "Gardener-*definitive* tomorrow water-*future-perfective* plants-*definitive* (lit.)" IT: I giardinieri domani bagneranno i fiori. [i d ardini'ɛ:ri dom'a:ni baɲer'anno i fi'o:ri] "The gardeners tomorrow water-*future* the flowers (lit.)" EN: Tomorrow the man will water the flowers.
Target Sentence	GR: Οι κηπουροί χθες [i cipur'i xθ'es] _____ "The gardeners yesterday _____ (lit)" (target: *πότισαν* τα λουλούδια [p'otisan ta lul'uðja] "watered the flowers") RU: Садовник вчера [sɐ'dovnʲik ft͡ʃ ɪ'ra] _____. "Gardener-*definitive* yesterday _____ (lit.)" (target: *полил* растения "watered plants-*definitive* (lit.)") IT: I giardinieri ieri [i d ardin i'ɛ:ri] _____. "The gardeners yesterday _____ (lit)" (target: *hanno bagnato* i fiori ['anno baɲ'a:to i fi'o:ri] "watered the flowers") EN: Yesterday the man _____. (target: *watered the flowers*)
Task 2	**Past Reference**
Source Sentence	GR: [ποτίζω τον κήπο [pot'izo ton c'ipo] "water the garden"] Οι κηπουροί χθες έσκαψαν τον κήπο. [i cipur'i xθ'es 'eskapsan ton c'ipo] "The gardeners yesterday dug the garden (lit.)" RU: [полить растения [pɐ'lʲ itʲ rɐ'sʲtʲenʲɪjə] "water plants-*definitive*"] Садовник вчера собрал грибы [sad'ovnʲik ft͡ʃ ʲir'a sʌbr'a gʲrʲib'y] "Gardener-*definitive* yesterday picked mushrooms (lit.)" IT: [bagnare i fiori [baɲ'a:re ˌi fi'o:ri] "water the flowers"] I giardinieri ieri hanno zappato l'orto. [i d ardini'ɛ:ri j'ɛ:ri anno dzap:'a:to l'ɔ:rto] "The gardeners yesterday have dug the garden (lit.)" EN: [water the flowers] Yesterday the man baked cakes.
Target Sentence	GR: Οι κηπουροί χθες [i cipur'i xθ'es] _____ "The gardeners yesterday _____" (target: *πότισαν* τον κήπο [p'otisan ton c'ipo] "watered the garden") RU: Садовник вчера [sɐ'dovnʲɪk ft͡ʃ ɪ'ra] _____ "Gardener-*definitive* yesterday _____" (target: *полил* растения [pɐlʲɪl rɐ'sʲtʲenʲɪjə] "watered plants-*definitive*") IT: I giardinieri ieri [i d ardini'ɛ:ri j'ɛ:ri]_____. "The gardeners yesterday _____ (lit.)" (target: *hanno bagnato* i fiori ['anno baɲ'a:to i fi'o:ri] "have watered the flowers (lit.)") EN: Yesterday the man _____. (target: *watered* the flowers)

Table 7. Examples of the subject-verb agreement condition of the Greek, Russian, Italian and English versions of the transformational sentence completion task (Task 1) and the non-transformational sentence completion task (Task 2).

Task 1	Agreement
Source Sentence	GR: Αύριο εγώ θα ποτίσω τα λουλούδια. ['avrio e 'o θa pot'iso ta lul'uðja] "Tomorrow I will water the flowers" RU: Сейчас мы поливаем растения [sʲɪjˈt͡ɕ æs 'mɨ pəlʲɪ'vajɪm rɐ's^{j}t^{j}enʲɪjə] "Now we water-*1st.pl.present-imperfective* plants-*definitive* (lit.)" IT: Domani io bagnerò i fiori. [dom'a:ni 'io baɲer'o i fi'o:ri] "Tomorrow I water-*1st.sg.future* the flowers (lit.)" EN: Every day I water the flowers.
Target Sentence	GR: Αύριο ο κηπουρός ['avrio o cipur'os] _____. "Tomorrow the gardener _____". (target: *θα ποτίσει* τα λουλούδια [θa pot'isi ta lul'uðja] "will water the flowers") RU: Сейчас садовники [sʲɪjˈt͡ɕ æs sɐ'dovnʲɪkʲɪ] _____ "Now gardeners-*definitive* _____" (target: *поливают* растения [pəlʲɪ'vajʉt rɐ's^{j}t^{j}enʲɪjə] "water-*3rd.pl.present*-imperfective plants-*definitive*") IT: Domani il giardiniere [dom'a:ni il d ardini'ɛ:re] _____. "Tomorrow the gardener _____". (target: *bagnerà* i fiori [baɲer'a i fi'o:ri] "water-*3rd.sg.future* the flowers (lit.)") EN: Every day the aunt _____. (target: *waters* the flowers)
Task 2	**Agreement**
Source Sentence	GR: [ποτίζω τα λουλούδια [pot'izo ta lul'uðja] "water the flowers"] Αύριο ο κηπουρός θα σκάψει τον κήπο. ['avrio o cipur'os θa sk'apsi ton c'ipo] "Tomorrow the gardener will dig the garden" RU: [поливать растения [pəlʲɪ'vatʲ rɐ's^{j}t^{j}enʲɪjə] "water plants"] Сейчас садовники собирают грибы [sʲijt͡ɕ ^{j}'ɑs sad'ovnʲikʲɪ sʌbʲir'aj͡ʊt ɡʲib'y] "Now gardeners-*definitive* pick-*3rd.pl.present-imperfective* mushrooms" IT: [bagnare i fiori [baɲ'a:re i fi'o:ri] "water the flowers"] Domani il giardiniere zapperà l'orto. [dom'a:ni il d ardini'ɛ:re dzap:e 'a l'ɔ:rto] "Tomorrow the gardener will hoe the garden" EN: [water the flowers] Every day the aunt bakes cakes.
Target Sentence	GR: Αύριο ο κηπουρός ['avrio o cipur'os] _____. "Tomorrow the gardener _____". (target: *θα ποτίσει* τα λουλούδια [θa pot'isi ta lul'uðja] "will water the flowers") RU: Сейчас садовники [s ɪjˈt͡ɕ æs'dovnʲɪkʲɪ] _____. "Now gardeners-*definitive* _____". (target: *поливают* растения [pəlʲɪ'vajʉt rɐ's^{j}t^{j}enʲɪjə] "water-*3rd.pl.present-imperfective* plants-*definitive* (lit.)") IT: Domani il giardiniere [dom'a:ni il d ardini'ɛ:re] _____. "Tomorrow the gardener _____". (target: *bagnerà* i fiori [baɲer'a i fi'o:ri] "water-*3rd.sg.future* the flowers (lit.)" EN: Every day the aunt _____. (target: *waters* the flowers)

morphosemantic (e.g., Lapointe, 1985) or psycholinguistic reasons. For example, present tense is acquired earlier than past tense or future tense (e.g., Pizzuto & Caselli, 1994; Szagun, 1978). As a consequence, better performance on present reference than on past or future reference (in languages in which future reference is made through non-present-tensed verbs) could be attributed to the age of acquisition advantage of present tense".

Since subject-verb Agreement has been consistently found to be better preserved than TR in aphasia (e.g., Friedmann & Grodzinsky, 1997; Fyndanis, Arcara, Christidou, et al., 2018; Gavarró & Martínez-Ferreiro, 2007; Wenzlaff & Clahsen, 2004), it was included as a control condition. That is, although this study focuses on TR, participants' performance on Agreement will also be reported, as potential task effects that do not relate to

encoding and retrieval processes will be easier to be determined if they appear in both the more demanding and less demanding conditions of Task 1 or Task 2. For example, if some participants find Task 2 more difficult than Task 1 due to reasons unrelated to retrieval or encoding processes, they may perform poorly in *both* the TR and Agreement conditions of Task 2, but not in those of Task 1.

In Task 1, participants were auditorily presented with a source sentence (e.g., *Yesterday the man watered the flowers*) and the beginning of a target sentence (e.g., *Tomorrow the man . . .*). They were required to complete the target sentence producing the correct form of the verb phrase (citation form of the target verb and its object) included in the source sentence (i.e., *will water the flowers*) (for examples, see Table 6). In the TR condition of this task, the participant had to encode a different TR-related abstract, prephonological value than that of the verb form that appeared in the source sentence, and then to retrieve a phonological form that matched the target prephonological TR-related value; the target phonological form of the verb, thus, always differed from the phonological form included in the source sentence. Task 1, therefore, appears to engage encoding and retrieval processes to a similar extent.

In Task 2, participants were cross-modally presented with the citation form of the target verb and its internal argument (i.e., object). The citation forms used were verb forms in 1st person, singular number, present tense and active voice in the Greek version of Task 2 (e.g., *ψήνω μπισκότα* "bake-1st.sg.present cookies"), and the infinitival forms of the target verb in the Russian, Italian and English versions of Task 2 (e.g., *bake cookies*; see also Tables 6 and 7).[4] Subsequently, participants were auditorily presented with a source sentence (e.g., *Tomorrow the man will water the flowers*) and the beginning of a target sentence (e.g., *Tomorrow the man . . .*) and were instructed to complete the target sentence producing the correct form of the verb phrase appearing on the computer screen (i.e., *will bake cookies*) (for more examples, see Tables 6 and 7). Therefore, in the TR condition of Task 2, the participant had to "copy and paste" the TR-related prephonological feature (e.g., +FUTURE) from the source sentence to the target sentence and then to retrieve the corresponding verb form. Therefore, Task 2 posed fewer encoding demands on the speaker's processing system than Task 1, and predominantly tapped into retrieval processes. Moreover, unlike in Task 1, participants had written support in Task 2 (i.e., cross-modal presentation of the citation form of the target verb and its internal argument).

Both tasks included 40 items tapping into TR production, of which 20 tapped past reference and 20 future reference. Task 1 and Task 2 also included 40 and 20 items tapping into subject-verb Agreement, respectively (for examples, see Table 7). In both tasks, the TR items were pseudorandomly interspersed with the Agreement items. The order of items was kept constant for all participants. Either task was split into two lists, and each participant completed one list.

Twenty regular transitive verbs taking one external and one internal argument (subject/agent and object/theme, respectively) were used in each language version of Task 1. All verbs were in active voice, and each verb appeared four times in Task 1. Specifically, in the TR condition, each verb appeared once in a past reference item (e.g., *Tomorrow the seamstress will iron the socks > Yesterday the seamstress ironed the socks*) and once in a future reference item (e.g., *Yesterday the seamstress ironed the socks > Tomorrow the seamstress will iron the socks*); in the subject-verb Agreement condition, each verb appeared once in a person agreement item (e.g., *Every day I iron the socks > Every day*

the seamstress irons the socks) and once in a number agreement item (e.g., *Every day the seamstresses iron the socks* > *Every day the seamstress irons the socks*). In the Greek and Italian versions of Task 1, subject-verb Agreement was tested within past reference and future reference contexts. In the Russian and English versions, however, subject-verb Agreement was tested only within a present tense/reference context, as in English the person and number features are not marked morphologically on past- and future-tensed verb forms, and in Russian, only present- and future-tensed verbs morphologically mark *both* person and number features. (In Russian, past-tensed verbs morphologically mark number and gender, but not person.) In present tense, there are only imperfective verbs in Russian; therefore, we used only imperfective verbs for the stimuli tapping into subject-verb Agreement. However, in the TR condition we used perfective verbs only, because the usage of present imperfective verb forms in future reference contexts, although plausible, could lead to ambiguous results. In all language versions of Task 1, all target verb forms in the Agreement condition were in 3rd person in order to avoid conversation-type errors (Fyndanis et al., 2013).[5] In the Agreement condition of the English Task 1, all experimental pairs tapping person agreement included transitions from 1st person and singular number to 3rd person and singular number. Transitions from verb forms in 2nd person and singular number to verb forms in 3rd person and singular number were not included, because the "2nd person cue" in English (*you*) is ambiguous (i.e., same for both singular and plural). Finally, all experimental pairs tapping number agreement in the English Task 1 included transitions from 3rd plural to 3rd singular. (We aimed for English-speaking participants to produce marked forms only in the Agreement condition because, in the present tense, English uses the unmarked form [e.g., *close*] for all three plural persons and for the first and second singular persons. Additionally, this unmarked form is also part of the infinitive.) In contrast, the number agreement (sub)conditions in the Greek, Russian and Italian versions of Task 1 included both transitions from 3rd plural to 3rd singular and transitions from 3rd singular to 3rd plural. The experimental items instantiating these two transition types were evenly distributed within the number agreement (sub)conditions of the Greek, Russian and Italian versions of Task 1. Furthermore, unlike in the English Task 1, person agreement in the Greek, Russian and Italian versions of Task 1 was tested within both singular and plural numbers.

The same 20 verbs that were included in Task 1 were also used in Task 2. However, in Task 2, each of these verbs appeared three times: twice in the TR condition (once in a past reference item, and once in a future reference item) and once in the subject-verb Agreement condition. (Due to the non-transformational nature of Task 2, it was not possible to distinguish between person agreement and number agreement.)

Rationale

The rationale behind this experimental design is reflected in (1) – (7).

(1) Worse performance on Task 1 than on Task 2 in the TR condition, coupled with high performance in the TR condition of Task 2, will point to a selective deficit in TR-related encoding processes.

The directionality of this line of reasoning stems from the encoding- and retrieval-related design features of Task 1 and Task 2. While both tasks place similar retrieval demands on the language production system, Task 2 imposes minimal encoding demands (i.e., primarily "copy-pasting") compared to Task 1. Given these similarities and

differences, better performance on Task 2 than on Task 1 may be directly attributed to a selective encoding deficit.

(2) If there is no compelling evidence that Task 2 is more difficult than Task 1 due to reasons unrelated to encoding and/or retrieval processes, comparably poor performance on Task 1 and Task 2 in the TR condition will point to a selective deficit in TR-related retrieval processes.

(3) Better performance on Task 1 than on Task 2 in the TR and/or Agreement conditions would indicate task effects unrelated to encoding and retrieval processes.

The directionality of this line of reasoning stems from two factors: (1) the encoding- and retrieval-related design features of Task 1 and Task 2, and (2) differences in the complexity of task instructions and level of intuitiveness between the two tasks. Regarding the first factor, as discussed in line reasoning (1), the between-task similarities and differences in encoding and retrieval demands suggest that better performance on Task 2 may be directly attributed to a selective encoding deficit. On the other hand, better performance on Task 1 compared to Task 2 can only be explained by assuming that, for some participants, Task 2 poses greater difficulty for reasons unrelated to encoding or retrieval processes. The second factor leading us to hypothesize that Task 2 may be more difficult than Task 1 (for reasons unrelated to encoding and retrieval processes) is Task 2's greater instructional complexity and lower level of intuitiveness.[6]

(4) Worse performance on Task 1 than on Task 2 in the TR condition, coupled with high performance in the TR condition of Task 2 and worse performance on past than on future reference in Task 1, will point to a selective deficit in past reference-related encoding processes.

(5) Worse performance on Task 1 than on Task 2 in the TR condition, coupled with high performance in the TR condition of Task 2 and worse performance on future than on past reference in Task 1, will point to a selective deficit in future reference-related encoding processes.

(6) If there is no compelling evidence that Task 2 is more difficult than Task 1 due to reasons unrelated to encoding and/or retrieval processes, comparably poor performance on Task 1 and Task 2 in the TR condition, and worse performance on past than on future reference in either task, will point to a selective deficit in past reference-related retrieval processes.

(7) If there is no compelling evidence that Task 2 is more difficult than Task 1 due to reasons unrelated to encoding and/or retrieval processes, comparably poor performance on Task 1 and Task 2 in the TR condition, and worse performance on future than on past reference in either task, will point to a selective deficit in future reference-related retrieval processes.

Procedure

In all four testing sites (Thessaloniki, Greece; Moscow, Russia; Lido/Venice, Italy; and Boston, USA), all participants were tested individually in a quiet environment by a trained clinical linguist (in Moscow) or a trained SLT (in Thessaloniki and Lido/Venice) or a trained psycholinguist or clinical fellow (in Boston). First, they were administered the non-transformational sentence completion task (Task 2), and then they completed the transformational sentence completion task (Task 1). We

acknowledge that, in general, varying the order in which the tasks are administered across participants is preferable to keeping the task order constant across participants, as this reduces the risk of task order effects. In the context of the present study, however, there is an advantage in keeping the task order constant across participants. This is because, when planning the study, we knew that the results would be analyzed at the individual level only, and, importantly, the emergence of a double dissociation between Task 1 and Task 2 would be a key finding, as this would be highly informative about the origin of each participant's observed deficit in TR production. Keeping the task order constant across participants ensures that, if a between-task double dissociation emerges, such a finding is "genuine" and cannot reflect task order effects.

Each participant completed one of the two stimuli lists of each task. The experimental lists were assigned to the participants in a pseudorandomized order. All participants completed the two tasks within one or two testing sessions.

Scoring criteria

In the TR conditions, all responses including verb forms matching the target time frame were scored as correct. Since aspectual adverbials were not included in the experimental items, responses including verb forms that matched the target time frame were scored as correct irrespective of the aspectual value they encoded. Likewise, in the subject-verb Agreement conditions, all responses including verb forms matching the target person and number were scored as correct. However, the scoring criteria for the Agreement condition in the English Task 1 and Task 2 are less straightforward. In the English tasks, all target sentences in this condition included verb forms in 3rd person, singular number and present tense. Some English-speaking PWAs, however, often produced verb forms in past or future tense, where subject-verb agreement is not marked overtly. When producing such verb forms in English, therefore, it is impossible to make agreement errors. Given this feature of the English morphology, we used two methods of scoring English-speaking participants' responses in the Agreement conditions. In scoring method 1, we did not remove any response and scored as incorrect responses only those responses that included uncontroversial agreement errors. In other words, responses that included verb forms in past tense (i.e., verb forms ending in -ed in the current tasks) or future tense (will + base infinitival forms[7] of verbs) were always scored as correct. In scoring method 2, we removed all responses that included verb forms in tenses where subject-verb agreement is not encoded overtly. As will be shown in the Results section (see Table 8), for all but one English-speaking PWA, the results of the comparisons between Task 1 and Task 2 in the Agreement condition were not affected by the choice of the scoring method.

Results

Comparisons between individual PWAs and control groups

All four control groups performed at ceiling (Greek-speaking control group: Task 1, TR condition, Mean [SD] = 98.1% [±5.3%]; Agreement condition, Mean [SD] = 99.4% [±1.8%]; Task 2, TR condition, Mean [SD] = 95.6% [±8.6%]; Agreement condition, Mean [SD] = 98.8%

Table 8. PWAs' accuracy performance on production of time reference and agreement in Task 1 and Task 2, comparisons between each PWA and the corresponding control group using the Crawford-Howell t-test, and within-participant comparisons using Fisher's exact test.

	TR-Transf (Task 1)	TR-Nontransf (Task 2)	TR-Transf vs TR-Nontransf	Agr-Transf (Task 1)	Agr-Nontransf (Task 2)	Agr-Transf vs Agr-Nontransf
Greek-speaking PWAs						
GP1	20/20 (100%)	7/20 (35%)	$p < .001$*	20/20 (100%)	3/10 (30%)	$p < .001$*
	$t = 0.338$, $p = .373$	$t = -6.644$, $p < .001$*		$t = 0.314$, $p = .381$	$t = -18.533$, $p < .001$*	
GP2	11/20 (55%)	5/20 (25%)	$p = .105$	13/20 (65%)	1/10 (10%)	$p = .007$*
	$t = -7.667$, $p < .001$*	$t = -7.740$, $p < .001$*		$t = -18.018$, $p < .001$*	$t = -23.920$, $p < .001$*	
GP3	13/20 (65%)	18/20 (90%)	$p = .127$	18/20 (90%)	10/10 (100%)	$p = .540$
	$t = -5.888$, $p < .001$*	$t = -0.614$, $p = .279$		$t = -4.924$, $p < .001$*	$t = 0.323$, $p = .378$	
GP4	11/20 (55%)	20/20 (100%)	$p = .001$*	19/20 (95%)	10/10 (100%)	$p = 1$
	$t = -7.667$, $p < .001$*	$t = 0.482$, $p = .322$		$t = -2.305$, $p = .027$*	$t = 0.323$, $p = .378$	
GP5	10/20 (50%)	10/20 (50%)	$p = 1$	14/20 (70%)	9/10 (90%)	$p = .372$
	$t = -8.556$, $p < .001$*	$t = -4.999$, $p < .001$*		$t = -15.399$, $p < .001$*	$t = -2.370$, $p = .025$*	
GP6	8/20 (40%)	1/20 (5%)	$p = .020$*	20/20 (100%)	10/10 (100%)	$p = 1$
	$t = -10.335$, $p < .001$*	$t = -9.932$, $p < .001$*		$t = 0.314$, $p = .381$	$t = 0.323$, $p = .378$	
GP7	20/20 (100%)	17/20 (85%)	$p = .231$	20/20 (100%)	10/10 (100%)	$p = 1$
	$t = 0.338$, $p = .373$	$t = -1.162$, $p = .142$		$t = 0.314$, $p = .381$	$t = 0.323$, $p = .378$	
GP8	17/20 (85%)	14/20 (70%)	$p = .451$	19/20 (95%)	10/10 (100%)	$p = 1$
	$t = -2.330$, $p = .026$*	$t = -2.807$, $p = .013$*		$t = -2.305$, $p = .027$*	$t = 0.323$, $p = .378$	
Russian-speaking PWAs						
RP1	16/20 (80%)	14/20 (70%)	$p = .716$	20/20 (100%)	9/10 (90%)	$p = .333$
	$t = -190.528$, $p < .001$*	$t = -1.808$, $p = .05$*		$t = 0.319$, $p = .378$	$t = -94.785$, $p < .001$*	
RP2	6/20 (30%)	2/20 (10%)	$p = .235$	11/20 (55%)	4/10 (40%)	$p = .670$
	$t = -669.242$, $p < .001$*	$t = -6.064$, $p < .001$*		$t = -28.404$, $p < .001$*	$t = -573.499$, $p < .001$*	
RP3	6/20 (30%)	6/20 (30%)	$p = 1$	18/20 (90%)	3/10 (30%)	$p = .002$*
	$t = -669.242$, $p < .001$*	$t = -4.645$, $p < .001$*		$t = -6.064$, $p < .001$*	$t = -669.242$, $p < .001$*	
RP4	7/20 (35%)	14/20 (70%)	$p = .056$	20/20 (100%)	9/10 (90%)	$p = .333$
	$t = -621.370$, $p < .001$*	$t = -1.808$, $p = .05$*		$t = 0.319$, $p = .378$	$t = -94.785$, $p < .001$*	
RP5	18/20 (90%)	16/20 (80%)	$p = .661$	19/20 (95%)	10/10 (100%)	$p = 1$
	$t = -94.785$, $p < .001$*	$t = -1.099$, $p = .149$		$t = -2.872$, $p = .008$*	$t = 0.957$, $p = .180$	
RP6	20/20 (100%)	7/20 (35%)	$p < .001$*	19/20 (95%)	4/10 (40%)	$p = .002$*
	$t = 0.957$, $p = .180$	$t = -4.291$, $p < .001$*		$t = -2.872$, $p = .008$*	$t = -573.499$, $p < .001$*	
RP7	16/20 (80%)	16/20 (80%)	$p = 1$	20/20 (100%)	10/10 (100%)	$p = 1$
	$t = -190.528$, $p < .001$*	$t = -1.099$, $p = .149$		$t = 0.319$, $p = .378$	$t = 0.957$, $p = .180$	
RP8	11/20 (55%)	9/20 (45%)	$p = .752$	12/20 (60%)	6/10 (60%)	$p = 1$
	$t = -429.885$, $p < .001$*	$t = -3.581$, $p = .003$*		$t = -25.212$, $p < .001$*	$t = -382.013$, $p < .001$*	

(*Continued*)

Table 8. (Continued).

	TR-Transf (Task 1)	TR-Nontransf (Task 2)	TR-Transf vs TR-Nontransf	Agr-Transf (Task 1)	Agr-Nontransf (Task 2)	Agr-Transf vs Agr-Nontransf
Italian-speaking PWAs						
IP1	12/20 (60%) $t = -373.230$, $p < .001$*	18/20 (90%) $t = -92.606$, $p < .001$*	$p = .065$	17/20 (85%) $t = -139.377$, $p < .001$*	6/10 (60%) $t = -373.230$, $p < .001$*	$p = .181$
IP2	4/20 (20%) $t = -747.396$, $p < .001$*	8/20 (40%) $t = -560.313$, $p < .001$*	$p = .301$	14/20 (70%) $t = -279.689$, $p < .001$*	4/10 (40%) $t = -560.313$, $p < .001$*	$p = .139$
IP3	2/20 (10%) $t = -840.937$, $p < .001$*	9/20 (45%) $t = -513.542$, $p < .001$*	$p = .031$*	8/20 (40%) $t = -560.313$, $p < .001$*	6/10 (60%) $t = -373.230$, $p < .001$*	$p = .442$
IP4	2/20 (10%) $t = -840.937$, $p < .001$*	9/20 (45%) $t = -513.542$, $p < .001$*	$p = .031$*	4/20 (20%) $t = -747.396$, $p < .001$*	1/10 (10%) $t = -840.937$, $p < .001$*	$p = .640$
IP5	3/20 (15%) $t = -794.167$, $p < .001$*	9/20 (45%) $t = -513.542$, $p < .001$*	$p = .082$	16/20 (80%) $t = -186.147$, $p < .001$*	2/10 (20%) $t = -747.396$, $p < .001$*	$p = .004$*
IP6	7/20 (35%) $t = -607.084$, $p < .001$*	17/20 (85%) $t = -139.377$, $p < .001$*	$p = .003$*	13/20 (65%) $t = -326.460$, $p < .001$*	8/10 (80%) $t = -186.147$, $p < .001$*	$p = .675$
English-speaking PWAs						
EP1	6/20 (30%) $t = -16.887$, $p < .001$*	8/20 (40%) $t = -19.782$, $p < .001$*	$p = .741$	16/20 (80%) $t = -9.502$, $p < .001$*	3/10 (30%) $t = -16.887$, $p < .001$*	$p = .015$*
				9/13 (69%)	3/10 (30%)	$p = .100$
EP2	7/20 (35%) $t = -15.656$, $p < .001$*	7/20 (35%) $t = -21.515$, $p < .001$*	$p = 1$	14/20 (70%) $t = -14.425$, $p < .001$*	10/10 (100%) $t = 0.345$, $p = .371$	$p = .074$
				11/17 (65%)	10/10 (100%)	$p = .057$
EP3	11/20 (55%) $t = -10.733$, $p < .001$*	6/20 (30%) $t = -23.247$, $p < .001$*	$p = .200$	16/20 (80%) $t = -9.502$, $p < .001$*	5/10 (50%) $t = -11.963$, $p < .001$*	$p = .116$
				3/7 (43%)	1/6 (17%)	$p = .559$
EP4	7/20 (35%) $t = -15.656$, $p < .001$*	3/20 (15%) $t = -28.444$, $p < .001$*	$p = .273$	16/20 (80%) $t = -9.502$, $p < .001$*	2/10 (20%) $t = -19.348$, $p < .001$*	$p = .004$*
				10/13 (77%)	2/10 (20%)	$p = .012$*
EP5	11/20 (55%) $t = -10.733$, $p < .001$*	3/20 (15%) $t = -28.444$, $p < .001$*	$p = .019$*	18/20 (90%) $t = -4.579$, $p = .002$*	1/10 (10%) $t = -21.810$, $p < .001$*	$p < .001$*
				7/8 (88%)	1/10 (10%)	$p = .003$*

(*Continued*)

Table 8. (Continued).

	TR-Transf (Task 1)	TR-Nontransf (Task 2)	TR-Transf vs TR-Nontransf	Agr-Transf (Task 1)	Agr-Nontransf (Task 2)	Agr-Transf vs Agr-Nontransf
EP6	3/20 (15%) $t = -20.579$, $p < .001$*	6/20 (30%) $t = -23.247$, $p < .001$*	$p = .451$	19/20 (95%) $t = -2.117$, $p = .039$* 15/16 (94%)	5/10 (50%) $t = -11.963$, $p < .001$* 5/10 (50%)	$p = .009$* $p = .018$*
EP7	8/20 (40%) $t = -14.425$, $p < .001$*	1/20 (5%) $t = -31.908$, $p < .001$*	$p = .020$*	18/20 (90%) $t = -4.579$, $p = .002$* 10/12 (83%)	10/10 (100%) $t = 0.345$, $p = .371$ 7/7 (100%)	$p = .540$ $p = .509$

In the English Agreement conditions, for each English-speaking PWA, the second row includes accuracy performance based on scoring method 2 (see the Scoring Criteria subsection in the Methods section). The symbol * indicates significant differences.

Table 9. PWAs' accuracy performance on production of past reference and future reference in Task 1 and Task 2, and within-participant comparisons using Fisher's exact test.

	Past-Transf (Task 1)	Future-Transf (Task 1)	Past-Transf vs Future-Transf (Task 1)	Past-Nontransf (Task 2)	Future-Nontransf (Task 2)	Past-Nontransf vs Future-Nontransf (Task 2)
Greek-speaking PWAs						
GP1	10/10 (100%)	10/10 (100%)	$p = 1$	7/10 (70%)	0/10 (0%)	$p = .003$*
GP2	3/10 (30%)	8/10 (80%)	$p = .070$	1/10 (10%)	4/10 (40%)	$p = .303$
GP3	5/10 (50%)	8/10 (80%)	$p = .350$	10/10 (100%)	8/10 (80%)	$p = .474$
GP4	10/10 (100%)	1/10 (10%)	$p < .001$*	10/10 (100%)	10/10 (100%)	$p = 1$
GP5	8/10 (80%)	2/10 (20%)	$p = .023$*	6/10 (60%)	4/10 (40%)	$p = .656$
GP6	7/10 (70%)	1/10 (10%)	$p = .020$*	1/10 (10%)	0/10 (0%)	$p = 1$
GP7	10/10 (100%)	10/10 (100%)	$p = 1$	9/10 (90%)	8/10 (80%)	$p = 1$
GP8	8/10 (80%)	9/10 (90%)	$p = 1$	7/10 (70%)	7/10 (70%)	$p = 1$
Russian-speaking PWAs						
RP1	7/10 (70%)	9/10 (90%)	$p = .582$	7/10 (70%)	7/10 (70%)	$p = 1$
RP2	5/10 (50%)	1/10 (10%)	$p = .141$	0/10 (0%)	2/10 (20%)	$p = .474$
RP3	6/10 (60%)	0/10 (0%)	$p = .011$*	2/10 (20%)	4/10 (40%)	$p = .629$
RP4	3/10 (30%)	4/10 (40%)	$p = 1$	7/10 (70%)	7/10 (70%)	$p = 1$
RP5	9/10 (90%)	9/10 (90%)	$p = 1$	7/10 (70%)	9/10 (90%)	$p = .582$
RP6	10/10 (100%)	10/10 (100%)	$p = 1$	3/10 (30%)	4/10 (40%)	$p = 1$
RP7	7/10 (70%)	9/10 (90%)	$p = .582$	8/10 (80%)	8/10 (80%)	$p = 1$
RP8	8/10 (80%)	3/10 (30%)	$p = .070$	7/10 (70%)	2/10 (20%)	$p = .070$
Italian-speaking PWAs						
IP1	3/10 (30%)	9/10 (90%)	$p = .020$*	9/10 (90%)	9/10 (90%)	$p = 1$
IP2	2/10 (20%)	2/10 (20%)	$p = 1$	4/10 (40%)	4/10 (40%)	$p = 1$
IP3	0/10 (0%)	2/10 (20%)	$p = .474$	3/10 (30%)	6/10 (60%)	$p = .370$
IP4	0/10 (0%)	2/10 (20%)	$p = .474$	0/10 (0%)	9/10 (90%)	$p < .001$*
IP5	2/10 (20%)	1/10 (10%)	$p = 1$	2/10 (20%)	7/10 (70%)	$p = .070$
IP6	0/10 (0%)	7/10 (70%)	$p = .003$*	8/10 (80%)	9/10 (90%)	$p = 1$
English-speaking PWAs						
EP1	2/10 (20%)	4/10 (40%)	$p = .629$	3/10 (30%)	5/10 (50%)	$p = .650$
EP2	4/10 (40%)	3/10 (30%)	$p = 1$	6/10 (60%)	1/10 (10%)	$p = .057$
EP3	10/10 (100%)	1/10 (10%)	$p < .001$*	6/10 (60%)	0/10 (0%)	$p = .011$*
EP4	2/10 (20%)	5/10 (50%)	$p = .350$	3/10 (30%)	0/10 (0%)	$p = .211$
EP5	4/10 (40%)	7/10 (70%)	$p = .370$	3/10 (30%)	0/10 (0%)	$p = .211$
EP6	1/10 (10%)	2/10 (20%)	$p = 1$	1/10 (10%)	5/10 (50%)	$p = .141$
EP7	8/10 (80%)	0/10 (0%)	$p < .001$*	1/10 (10%)	0/10 (0%)	$p = 1$

[±3.5%]; Russian-speaking control group: Task 1, TR condition, Mean [SD] = 100% [±0.0%]; Agreement condition, Mean [SD] = 99.5% [±1.5]; Task 2, TR condition, Mean [SD] = 95.5% [±13.5%]; Agreement condition, Mean [SD] = 100% [±0.0%]; Italian-speaking control group: Task 1, TR condition, Mean [SD] = 100% [±0.0]; Agreement condition, Mean [SD] = 100% [±0.0]; Task 2, TR condition, Mean [SD] = 100% [±0.0]; Agreement condition, Mean [SD] = 100% [±0.0]; English-speaking control group: Task 1, TR condition, Mean [SD] = 98.6% [±3.8%]; Agreement condition, Mean [SD] = 99.3% [±1.9%]; Task 2, TR condition, Mean [SD] = 97.1% [±2.7%]; Agreement condition, Mean [SD] = 98.6% [±3.8%]). To determine which PWAs were impaired in morphosyntactic production, we compared each PWA's performance in the TR and Agreement conditions in Task 1 and Task 2 with the performance of the corresponding control group using the Crawford-Howell t-test (Crawford & Garthwaite, 2002, 2012; Crawford & Howell, 1998; Crawford et al., 2010). As shown in Table 8, all PWAs but GP7 were impaired in TR in Task 1 and/or Task 2, and all but three PWAs (GP6, GP7, and RP7) were impaired in production of subject-verb agreement in at least one of the two tasks (When the standard deviation of the control group is 0, the program Singlims_ES.EXE ––which we used to perform the Crawford-Howell t-test––yields no results. In comparisons where the standard deviation of a control group's performance was 0 [i.e., Russian control group in the TR condition of Task 1 and in the Agreement condition of Task 2, and Italian control group in both conditions in Task 1 and Task 2], we arbitrarily added a single error in the control group's data set to tackle this problem, as we did in Fyndanis, Arcara, Capasso, et al., 2018).

Within-participant with aphasia comparisons

Within-subject comparisons were performed using Fisher's exact test. As shown in Table 8, in the TR condition, three Greek-speaking PWAs (GP1, GP4 and GP6), one Russian-speaking PWA (RP6), three Italian-speaking PWAs (IP3, IP4 and IP6) and two English-speaking PWAs (EP5 and EP7) showed between-task dissociations. A double dissociation emerged, as GP1, GP6, RP6, EP5 and EP7 performed better on Task 1 than on Task 2, whereas GP4, IP3, IP4 and IP6 performed worse on Task 1 than on Task 2. In the Agreement condition, nine PWAs (namely, GP1, GP2, RP3, RP6, IP5, EP1,[8] EP4, EP5 and EP6) exhibited between-task dissociations that had the same direction: Task 2 elicited worse performances than Task 1.

Furthermore, as shown in Table 9, dissociations between past and future reference were exhibited by GP1 (in Task 2), GP4 (in Task 1), GP5 (in Task 1), GP6 (in Task 1), RP3 (in Task 1), IP1 (in Task1), IP4 (in Task 2), IP6 (in Task 1), EP3 (in both tasks) and EP7 (in Task 1). In fact, a double dissociation between past and future reference emerged, as GP1, GP4, GP5, GP6, RP3, EP3 and EP7 fared better on past reference than on future reference, whereas IP1, IP4 and IP6 exhibited the opposite pattern. It should also be noted that, of the 10 PWAs who exhibited past-future dissociations, only one (EP3) displayed this dissociation in both tasks. Of the remaining nine PWAs, seven exhibited dissociations between past and future reference in Task 1 (GP4, GP5, GP6, RP3, IP1, IP6 and EP7), and only two displayed such dissociations in Task 2 (GP1 and IP4).

Finally, 13 PWAs exhibited dissociations between TR and subject-verb agreement (namely, GP4, GP5, GP6, RP3, RP4, IP2, IP5, EP1, EP2, EP4, EP5, EP6 and EP7), with all of

them performing significantly better on the latter than on the former (all p-values are given in the Appendix).

Discussion

The primary goal of the present study was to tease apart selective TR-related encoding deficits and TR-related retrieval deficits in PWAs. To this end, we administered two sentence completion tasks tapping production of past reference, future reference, and subject-verb Agreement (with the latter serving as a control condition) to Greek-speaking, Russian-speaking, Italian-speaking and English-speaking PWAs and language-matched, age-matched and education-matched healthy control participants. Task 1 was a transformational sentence completion task tapping encoding and retrieval processes to a similar extent, whereas Task 2 was a non-transformational completion task predominantly tapping retrieval processes.

All control groups performed at ceiling. Comparisons between each individual PWA and the corresponding control group revealed that all PWAs except GP7 were impaired in TR production in Task 1 and/or Task 2, and all but three PWAs (GP6, GP7 and RP7) were impaired in production of subject-verb agreement in at least one of the two tasks. This finding was not unexpected, as impaired morphosyntactic production is common in stroke-induced aphasia. It was long believed that impaired verb-related morphosyntactic production was only present in nonfluent aphasia, but recent evidence indicates that also persons with fluent aphasia can be impaired in verb-related morphosyntactic production (e.g., Bos & Bastiaanse, 2014; Dragoy & Bastiaanse, 2013; Fyndanis, Arcara, Capasso, et al., 2018; Jonkers & De Bruin, 2009; Kljajevic & Bastiaanse, 2011).

However, it appears that, not only GP7 (see above), but also GP1 and RP6 had no TR-related deficits. Although GP1 and RP6 performed 35% correct in the TR condition of Task 2, they both performed 100% correct on TR in Task 1. Their ceiling TR performance in Task 1 (i.e., the "encoding and retrieval task") suggests that their poor TR performance in Task 2 (i.e., the "retrieval task") is attributable to task effects unrelated to retrieval (and encoding) deficits. The evidence that Task 2 was harder than Task 1 for GP1 and RP6 is compelling, as they both fared better on Task 1 than on Task 2 not only in the TR condition but also in the Agreement condition (see Table 8).

Moreover, all PWAs who exhibited dissociations between TR and subject-verb agreement ($N = 13$) performed significantly worse on TR than on agreement. This is consistent with earlier findings showing that subject-verb agreement is better preserved than TR in aphasia (e.g., Friedmann & Grodzinsky, 1997; Fyndanis, Arcara, Capasso, et al., 2018; Gavarró & Martínez-Ferreiro, 2007; Wenzlaff & Clahsen, 2004).

As will be shown in the remainder for this section, PWAs' individual patterns of results enable us to identify both PWAs with selective TR-related encoding deficits and PWAs with selective TR-related retrieval deficits. Before proceeding to the next subsections, it is important to note that, for several participants, Task 2 was more difficult than Task 1 due to reasons unrelated to retrieval and encoding processes. This is supported by two key observations. First, some PWAs (namely, GP1, GP6, RP6, EP5, and EP7) performed better in the TR condition of Task 1 (the "encoding and retrieval task") than of Task 2 (the "retrieval task"; see Table 8). Second, nine between-task dissociations emerged in the Agreement

condition (see the results of GP1, GP2, RP3, RP6, IP5, EP1, EP4, EP5, and EP6 in Table 8), and showing the same pattern: Task 2 consistently elicited worse performances than Task 1.

PWAs with selective TR-related encoding deficits

As it will be shown below, there were six PWAs with selective TR-related encoding deficits: GP3, GP4, RP5, RP7, IP1, and IP6. Since GP4 and IP6 performed 100% and 85% correct, respectively, in the TR condition of Task 2 (the "retrieval task"), and only 55% and 35% correct, respectively, in the TR condition of Task 1 (the "encoding and retrieval task"), it is safe to conclude that they had selective TR-related encoding deficits. These PWAs' worse performance on Task 1 than on Task 2 was driven by what distinguishes Task 1 from Task 2, i.e., TR-related encoding demands. It is very likely that also IP1 had a selective TR-related encoding deficit, as he performed 90% correct in the TR condition of Task 2 and 60% correct in the TR condition of Task 1. The evidence for IP1, however, is weak as the between-task difference was marginally significant.

Although GP3, RP5 and RP7 did not exhibit dissociations between Task 1 and Task 2 in the TR condition, they were found impaired in Task 1 but not in Task 2 (in TR), as the comparisons between their individual performances and the performances of the corresponding control groups show (Table 8). Given this, and since they performed 65–90% correct in the TR condition of Task 1, we conclude that these three PWAs had selective mild-to-moderate encoding deficits. (Along the same lines, GP3's and RP5's performances on Agreement in Task 1 and Task 2 suggest that they also had selective mild agreement-related encoding deficits.)

Of the above six PWAs with selective TR-related encoding deficits, only three exhibited dissociations between past and future reference: GP4, IP1, and IP6 (see Table 9). To provide a more precise characterization of these PWAs' deficits, GP4's better performance on past than on future reference in Task 1 suggests a selective future reference-related encoding deficit. In contrast, IP1's and IP6's worse performances on past than on future reference in Task 1 suggests a selective past reference-related encoding deficit.

PWAs with selective TR-related retrieval deficits

As will be explained in this subsection, there were eight PWAs with selective TR-related retrieval deficits: GP5, GP8, RP1, RP2, RP8, IP2, EP2, and EP3. The comparably poor performance of the above participants in the TR condition of the two tasks, coupled with the lack of evidence that Task 2 was harder than Task 1 for any of these PWAs due to reasons unrelated to encoding and/or retrieval processes, points to selective deficits in TR-related retrieval processes. This is so because the "common denominator" in Task 1 and Task 2 is the amount of retrieval demands; the two tasks do not differ in retrieval demands. Moreover, GP5's and EP3's significantly better performances on past than on future reference in Task 1 and/or Task 2 suggest that they had selective future reference-related retrieval deficits. Finally, RP2's, RP8's and EP3's comparably poor performances on Task 1 and Task 2 in *both* the TR and subject-verb Agreement conditions suggest that they had selective deficits not only in TR-related retrieval processes, but also in Agreement-related retrieval processes.

PWAs with both TR-related encoding and retrieval deficits

IP3 and IP4 performed 45% correct in the TR condition of Task 2 and 10% correct in the TR condition of Task 1 (with these between-task differences being significant – see Table 8). Given that they both performed poorly in the "retrieval task" (i.e., Task 2), their overall patterns of performance could be accounted for by assuming that IP3 and IP4 had both TR-related encoding and retrieval deficits.

PWAs with unclear origin of their impaired TR production

There were 10 PWAs with unclear source of TR impairment: GP2, GP6, RP3, RP4, IP5, EP1, EP4, EP5, EP6, and EP7. Before discussing the interpretation of these PWAs' results, it should be noted that, as shown in Table 8, all nine PWAs who performed poorly in the Agreement condition of Task 2, and significantly worse in Task 2 than in Task 1 in the same condition (i.e., GP1, GP2, RP3, RP6, IP5, EP1, EP4, EP5 and EP6), also performed poorly in the TR condition of Task 2 (15–45% correct). In contrast, there were PWAs who fared poorly on TR in Task 2 but high on Agreement in Task 2 (e.g., GP5: TR = 50%, Agreement = 90%; GP6: TR = 5%, Agreement = 100%; EP2: TR = 35%, Agreement = 100%; EP7: TR = 5%, Agreement = 100%). Most importantly, in some PWAs (GP6 and EP7), task effects emerged in TR but not in Agreement (see Table 8). The above associations and dissociations suggest that, when a task effect emerges in Agreement (due to reasons unrelated to retrieval and encoding processes), this effect seems to be present in TR as well. In some PWAs, however, such a task effect may only emerge in the most challenging morpho-syntactic category, namely TR. Further evidence for this conclusion is provided by the fact that both GP6 and EP7 (the only PWAs who exhibited a task effect in TR but not in Agreement) performed significantly worse on TR than on subject-verb Agreement in both tasks (for *p*-values, see Appendix).

Just like IP3 and IP4 (see subsection above), RP4 and IP5 might have had both TR-related encoding and retrieval deficits as, although they both performed worse on Task 1 (35% correct for RP4 and 15% correct for IP5) than on Task 2 in the TR condition, their TR performances in Task 2 were still low (70% correct for RP and 45% correct for IP5). However, the between-task differences in TR were only marginally significant (see Table 8), and thus the evidence for the above interpretation of RP4's and IP5's results is weak. Therefore, we cannot rule out the possibility that RP4 and IP5 had selective TR-related retrieval deficits.

GP6 and EP7 showed similar patterns of performance. Both participants performed better on Task 1 (the "encoding and retrieval task") than on Task 2 (the "retrieval task") in the TR condition, with 40% correct in Task 1 compared to 5% in Task 2. This suggests task effects unrelated to TR-related encoding and retrieval processes. However, despite performing better on Task 1, their 40% accuracy still indicates poor performance on TR, suggesting that their overall patterns of TR performance cannot be explained solely by task effects. Given the poor TR performance in Task 1 and the increased demands of Task 2 due to reasons unrelated to retrieval and encoding processes, along with the fact that both participants performed significantly better on past reference than on future reference in Task 1 (see Table 9), their overall patterns of TR performance may reflect a combination of TR-related encoding and retrieval deficits, which affect future reference

more than past reference, and the increased demands of Task 2, which are unrelated to the above deficits. Alternatively, GP6's and EP7's overall patterns of performance on TR could be attributed to the combined effects of a selective TR-related encoding deficit and a task effect unrelated to retrieval and encoding processes. The absence of a dissociation between past and future reference in Task 2 in both participants reflects floor effects as they both performed 5% correct in the TR condition of Task 2. The fact that, in both GP6 and EP7, Task 2's increased demands emerged in TR but not in Agreement suggests that the latter morphosyntactic category was very easy for them (they performed 90–100% correct on Agreement in both tasks), so there was no bottleneck effect for these participants in the Agreement condition of Task 2. (When bottleneck effects emerge in this condition in Task 2, poor performance on Agreement reflects the combined effects of Task 2's increased demands due to reasons unrelated to retrieval and encoding processes and the "psycholinguistic demands" that Agreement poses on participants' processing system.)

EP5's overall pattern of performance is similar to that of GP6 and EP7 except that he showed no dissociation between past and future reference. That is, not only for GP6 and EP7 but also for EP5 was Task 2 more difficult than Task 1 due to reasons unrelated to retrieval and encoding processes. This is so because he performed significantly worse on Task 2 than on Task 1. However, just like in GP6 and EP7, his performance in the TR condition of the "easier task" (i.e., Task 1) (55% correct) suggests that he had TR-related encoding and/or retrieval deficits. It is impossible to tease apart encoding and retrieval processes in EP5 because it is hard to estimate what his TR performance level in Task 2 would be if the two tasks were equally demanding. Similar to GP6 and EP7, EP5's overall performance pattern suggests either a combined TR-related encoding and retrieval deficit or a selective TR-related encoding deficit.

Other PWAs with unclear origins of their TR impairment include RP3, EP1, and EP6. Although they all fared comparably poorly in Task 1 and Task 2 in the TR condition (15–40% correct), which *prima facie* would suggest a selective TR-related retrieval deficit, their performances on Agreement show that, for them, Task 2 was much harder than Task 1 due to reasons unrelated to retrieval and encoding processes (see Table 8 – although they performed 80–95% correct in the Agreement condition of Task 1, which equally tapped encoding and retrieval processes, they only performed 30–50% correct in the Agreement condition of Task 2, which predominantly tapped retrieval processes). This conclusion led us to speculate that, for these participants, if Task 2 is harder than Task 1 in the Agreement condition, the same should hold for the TR condition (see first paragraph of current subsection). Therefore, if the two tasks had been equally hard for these participants, their TR performance would have been better in Task 2 than in Task 1. However, we cannot estimate what their level of performance on Task 2 would be, which leaves us with two possibilities: If they performed at ceiling on Task 2, their better performance compared to Task 1 would suggest selective TR-related encoding deficits. Conversely, if their performance on Task 2 were relatively low but still significantly better than on Task 1, their overall performance pattern would indicate both TR-related encoding and retrieval deficits.

Performances in the Agreement condition reveal that Task 2 was more difficult than Task 1 also for GP2 and EP4 (see Table 8). It is uncertain whether GP2's and EP4's TR performance would have been higher in Task 2 than in Task 1 if the two tasks had

been equally hard, because they performed better in the TR condition of Task 1 (GP2: 55% correct; EP4: 35% correct) than of Task 2 (GP2: 25% correct; EP4: 15% correct). We cannot rule out therefore any of the following explanations for GP2's and EP4's overall performance patterns: They might have had selective TR-related retrieval deficits (if they performed better in the TR condition of Task 2, though their TR performance in Task 2 remained relatively low and comparable to Task 1), or selective TR-related encoding deficits (if they performed notably better in the TR condition of Task 2, with their TR performance being high and significantly better than in Task 1).

Is the direction of past-future dissociations related to whether the source of the impairment is a selective encoding deficit or a selective retrieval deficit?

Of the six PWAs with clearly selective TR-related encoding deficits (i.e., GP3, GP4, RP5, RP7, IP1, and IP6), three (GP4, IP1 and IP6) exhibited dissociations between past and future reference. One (GP4) performed better on past than on future reference, and two (IP1 and IP6) exhibited the opposite pattern. Of the eight participants with clearly selective TR-related retrieval deficits (i.e., GP5, GP8, RP1, RP2, RP8, IP2, EP2 and EP3), only two (GP5 and EP3) displayed past-future dissociations. They both fared better on past than on future reference in Task 1 and/or Task 2. Therefore, the present study does not lend empirical support to Fyndanis, Arcara, Capasso, et al.'s (2018) speculation that PWAs with selective TR-related retrieval deficits might be more impaired in past reference than in future reference, and PWAs with selective TR-related encoding deficits might be more impaired in future reference than in past reference. Relatedly, the double dissociation between past and future reference, which emerged in the PWAs with selective TR-related encoding deficits, contradicts the idea that the direction of past-future dissociations depends on whether, in a given PWA, the origin of impaired TR production is a selective encoding deficit or a selective retrieval deficit. This idea would be further challenged if we identified (in future research) PWAs with selective TR-related retrieval deficits performing worse on past than on future reference. Studies with larger numbers of PWAs would be better suited to further address this subsection's question.

Other remarks

More past-future dissociations in Task 1 than in Task 2

Dissociations between past and future reference were more marked in Task 1 ($N = 8$) than in Task 2 ($N = 3$). In our view, this is because Task 1 is equally demanding for both encoding and retrieval processes, whereas Task 2 is more demanding for retrieval than for encoding processes. Given that there are selective TR-related encoding and retrieval deficits that may be specific to past reference or future reference, some PWAs exhibit past-future dissociations because of encoding (and not retrieval) deficits differentially affecting past and future reference (e.g., GP4, IP1 and IP6 – see "PWAs with selective TR-related encoding deficits" subsection); others exhibit such dissociations because of retrieval (and not encoding) deficits differentially affecting the above time frames (e.g., GP5 and EP3 – see "PWAs with selective TR-related retrieval deficits" subsection); and others display past-future dissociations due to both encoding and retrieval deficits that differentially affect past and future reference (e.g., IP4 – see "PWAs with both TR-related encoding and retrieval

deficits" subsection, as well as Table 9). Due to its design features and inclusive nature, Task 1 is better suited than Task 2 to capture past-future dissociations across all three of the aforementioned "deficit types". In contrast, Task 2 is more likely to capture past-future dissociations related to retrieval deficits that differentially affect the time frames under investigation, rather than those related to encoding deficits.

Is the direction of the dissociation between past and future reference dependent on the language?

All three Italian-speaking PWAs who exhibited dissociations between past and future reference (IP1, IP4 and IP6) performed better on future than on past reference. In contrast, all seven Greek-, Russian- and English-speaking PWAs that showed dissociations between past and future reference (GP1, GP4, GP5, GP6, RP3, EP3, EP7) performed worse on future than on past reference. However, given the small numbers of PWAs in each language, these results may not be representative of the whole populations of Italian-, Greek-, Russian- and English-speaking PWAs. In Fyndanis, Arcara, Capasso, et al. (2018), for example, a double dissociation in Greek aphasia was observed; one participant (P4) performed better on past reference than on future reference, while another participant (P6) performed worse on past reference than on future reference. Future studies on each of the above languages, with sufficiently large numbers of PWAs, should further explore whether the direction of the dissociation between past and future reference depends on the specific language.

Relation between aphasia type and TR deficits

The present study demonstrates that impaired TR production is observed in both nonfluent and fluent aphasia (for nonfluent participants with severe TR deficits, see GP2, GP3, GP4, GP5, RP2, RP3, RP4, RP8, IP1, IP2, IP3, IP4, IP5, IP6 and EP5; and for fluent participants with severe TR deficits, see GP6, EP1, EP2, EP3, EP4, EP6 and EP7). This is in line with Bos and Bastiaanse (2014), Fyndanis, Arcara, Capasso, et al. (2018) and Cordonier et al. (2024).

Moreover, of the eight PWAs with selective TR-related retrieval deficits, five had been diagnosed with nonfluent aphasia (i.e., GR5, RP1, RP2, RP8, IP2), and three with fluent aphasia (i.e., GP8, EP2 and EP3). All six PWAs with selective TR-related encoding deficits had been diagnosed with nonfluent aphasia. Nevertheless, this finding does not necessarily mean that selective TR-related encoding deficits are only observed in nonfluent aphasia; in our study, the sample size was relatively small ($N = 29$) and there was an uneven distribution of participants with nonfluent aphasia ($N = 20$) and participants with fluent aphasia ($N = 9$). This lack of balance between nonfluent and fluent participants may have biased the results.

Were there task order effects?

As mentioned in the Methods section, we kept the task order constant; all participants first completed the non-transformational sentence completion task (Task 2), and then the transformational sentence completion task (Task 1). Since all 12 PWAs who exhibited between-task dissociations in the Agreement condition performed worse in Task 2 than in Task 1 (see Table 8), one could ask if task order rendered Task 2 more difficult than Task 1. In our view, the order in which the tasks were administered did not significantly affect participants' performance for the following reason: of the nine PWAs who exhibited

between-task dissociations in the TR condition, four participants (GP4, IP3, IP4 and IP6) performed better on Task 2 than on Task 1, and five participants (GP1, GP6, RP6, EP5 and EP7) performed better on Task 1 than on Task 2 (see Table 8). That is, despite the fixed order of Task 1 and Task 2 across participants, a double dissociation emerged between the two tasks in the TR condition, unlike in the Agreement condition. Since task order was constant, this result could not be attributed to task order effects.

To the best of our knowledge, this is the first study to propose an experimental design that enables teasing apart TR-related encoding deficits and TR-related retrieval deficits. This is a significant methodological advancement as the proposed design can be applied not only to PWAs with impaired production of TR, but in general to individuals with language disorders and neurotypical older individuals who have difficulty producing any verb-related morphosyntactic/morphosemantic category. Production of grammatical aspect, for example, has been reported to be impaired in Greek aphasia, dementia of the Alzheimer type, multiple sclerosis, and mild cognitive impairment (Fyndanis et al., 2012, 2013, 2020, 2022; Fyndanis, Arcara, Capasso, et al., 2018; Manouilidou et al., 2020; Nanousi et al., 2006; Varlokosta et al., 2006). The proposed design, therefore, allows the clinician to make more detailed assessments of their clients' morphosyntactic abilities and more precise diagnoses of the nature of each morphosyntactic deficit. Locating the exact source of each client's morphosyntactic deficit with precision could in turn lead to better-informed and, thus, more efficacious treatment programs for individuals with impaired verb-related morphosyntactic production.

In conclusion, we provided cross-linguistic evidence that the experimental design proposed here permits teasing apart selective TR-related encoding deficits and selective TR-related retrieval deficits. This design is clinically relevant as it enables a more precise psycholinguistic assessment regarding the ability of PWAs to produce TR, and helps the clinician identify the specific source of the TR production impairment for each PWA. Future translational research should focus on developing treatment programs that would target selective TR-related encoding deficits or TR-related retrieval deficits.

Limitations of the study

In all four languages represented in the present study, the healthy control participants outperformed the PWAs, and between-task dissociations emerged in several PWAs, which demonstrates that the proposed experimental design is sensitive to TR production impairments, as well as to the differential impact of TR-related encoding vs. retrieval demands and to task effects. However, the tasks included in the proposed experimental design would be more sensitive if they consisted of more items – if, for example, either condition (i.e., TR condition and subject-verb Agreement condition) included 30 or 40 instead of 20 items. Arguably, this would permit more between-task dissociations to be detected, which would presumably lead to a more accurate diagnosis regarding the locus of impairment in TR production for each PWA.

Conclusions

This study aimed at teasing apart TR-related encoding deficits and TR-related retrieval deficits in aphasia. To this end, we developed two sentence completion tasks (one transformational and one non-transformational) that were administered to Greek,

Russian, Italian and English-speaking PWAs. The results provided cross-linguistic evidence that the proposed experimental design provides a sound basis for disentangling TR-related encoding deficits from TR-related retrieval deficits. This is evidenced by the fact that the pattern of performance of some PWAs on the two tasks suggests that these participants had selective TR-related encoding deficits, whereas the pattern of performance of other PWAs points to selective TR-related retrieval deficits. This is the first study to propose an experimental design that enables teasing apart TR-related encoding deficits and TR-related retrieval deficits. This experimental design could be adapted to tease apart encoding and retrieval processes involved in the production of other morphosyntactic/morphosemantic categories that have been found to be prone to impairment in aphasia and related disorders, as well as in healthy aging (e.g., grammatical aspect). The proposed design, therefore, enables clinicians to conduct in-depth evaluations of their clients' morphosyntactic skills, facilitating more accurate diagnoses of the specific nature of each morphosyntactic impairment. Pinpointing the precise origin of a client's morphosyntactic deficits has the potential to enhance the development of well-informed and consequently more effective treatment programs targeting morphosyntactic/morphosemantic impairments.

Notes

1. Similar error types were reported in Faroqi-Shah and Thompson (2004) and Lee et al. (2008).
2. As mentioned above, it has been argued that, unlike reference to the non-past, reference to the past is discourse linked (Zagona, 2003, 2013). Moreover, since reference to the future refers to possible worlds, it involves more abstract representations as compared to reference to the past.
3. In the production segment of the TART, participants are presented with two horizontally arranged pictures, each accompanied by the infinitival form of a verb. The experimenter initially directs attention to the picture on the left, providing a description (e.g., *For this picture, you can say the man just ate an apple*), then shifts to the picture on the right and initiates its description. At a certain point, the experimenter interrupts the utterance, and the participant is instructed to complete it by producing the missing verb phrase, which includes the target finite verb form (e.g., *For this picture, you can say the man just*. . . [target: . . .peeled an apple]).
4. In Greek, there are no infinitives.
5. As mentioned in Fyndanis et al. (2013), when the target verb form is in 2nd person––and therefore when the cue is a personal pronoun in 2nd person (*you* in English)––some participants often interpret the cue/personal pronoun *you* included in the target sentence as an invitation to speak about themselves, which leads in their producing verb forms in 1st person and singular number, as if they conversed with the examiner. Likewise, when the target sentence includes the cue *I*, some participants often produce verb forms in 2nd person and singular number. Such errors, therefore, are conversation-type errors and not genuine agreement errors, as they result from violation of the task instructions.
6. As detailed above, in Task 2, participants are first cross-modally presented with the citation form of the target verb and its internal argument (object). They then listen to a source sentence containing a different verb while continuing to view the target verb and its internal argument on a computer screen. Finally, they listen to the beginning of the target sentence and must complete it by producing the appropriate form of the target verb and its internal argument. In contrast, Task 1 is more intuitive. It involves listening to a source sentence and the beginning of a target sentence, and then completing the target sentence by producing

a different form of the verb included in the source sentence, along with its internal argument, which also appears in the source sentence.
7. Base infinitives are defined as infinitives without *to*.
8. EP1 showed a between-task dissociation in the Agreement condition only based on scoring method 1 (see Scoring Criteria subsection).

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Appendix

Dissociations between Time Rereference and subject-verb Agreement (within-participant [with aphasia] and within-task comparisons using Fisher's exact test)

GP4: TR < Agreement in Task 1, p = .008
GP5: TR < Agreement in Task 2, p = .049
GP6: TR < Agreement in Task 1, p < .001
GP6: TR < Agreement in Task 2, p < .001
RP3: TR < Agreement in Task 1, p < .001
RP4: TR < Agreement in Task 1, p < .001
IP2: TR < Agreement in Task 1, p = .004
IP5: TR < Agreement in Task 1, p < .001
EP1: TR < Agreement in Task 1, p = .004
EP2: TR < Agreement in Task 2, p = .001
EP4: TR < Agreement in Task 1, p = .010
EP5: TR < Agreement in Task 1, p = .031
EP6: TR < Agreement in Task 1, p < .001
EP7:TR < Agreement in Task 1, $p = .002$
EP7:TR < Agreement in Task 2, $p < .001$