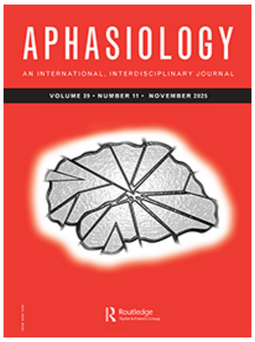

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Classification of lexical retrieval impairments in primary progressive aphasia

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ABSTRACT

Background: Lexical retrieval impairments are a hallmark feature of Primary Progressive Aphasia (PPA) and play a central role in diagnosis and clinical management. Lexical retrieval is a multiple-component process, and impairment to each of the components of this process gives rise to a different pattern of deficit. However, most current research on lexical retrieval in PPA categorizes deficits only broadly as either semantic or phonological, without identifying the exact functional locus of impairment or accounting for finer dissociations within these broad classifications.

Aims: The current study applies a cognitive neuropsychological model of lexical retrieval and a corresponding classification framework to systematically categorize lexical retrieval impairments in 40 Hebrew-speakers with PPA.

Methods: We used a comprehensive assessment battery that includes picture-naming, word-picture matching, picture association, and nonword repetition, and conducted a detailed error analysis. The classification algorithm considers success rate in tasks compared to age-matched norms and error types for each participant.

Results: We identified lexical retrieval impairments in 75% of the participants. Selective impairments were found in each of the five cognitive components involved in lexical retrieval, with some participants diagnosed with more than one impaired component. The impaired components include the conceptual system (5 participants), the semantic lexicon (13 participants), the phonological output lexicon or the connection between semantic and phonological lexicons (18 participants), and the phonological output buffer (19 participants). Each impairment was associated with a distinct pattern of errors in both naming and in the additional language assessments. The findings reveal dissociations between different types of lexical retrieval impairments, reflecting the modular nature of lexical retrieval.

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Conclusions: Lexical retrieval deficits in PPA are prevalent and diverse. Capturing this diversity requires a componential, theory-driven model and classification framework. This framework more accurately describes the functional locus of impairment compared to the variant-based classification and allows for patients to be diagnosed with more than one type of impairment. Accurate diagnosis and classification are essential for effective treatment and the development of communication strategies for patients with PPA.

1. Introduction

Word-finding difficulties are one of the most common complaint among patients with Primary Progressive Aphasia (PPA) and their caregivers (Rohrer et al., 2008) and among the first to appear (Mesulam et al., 2012). Consequently, lexical retrieval is routinely assessed for PPA in both research and clinical contexts, anis considered a hallmark diagnostic criterion as reflected in the consensus classification of all three variants of the condition (Gorno-Tempini et al., 2011).

The cognitive neuropsychological literature recognizes lexical retrieval as a multi-staged process that involves several distinct cognitive components. Research on other neurological conditions, such as post-stroke aphasia and developmental language disorders, has demonstrated that each of the stages in this process can be selectively impaired (Friedmann et al., 2013; Howard & Gatehouse, 2006; Kay et al., 1996; Nickels, 1995, 1997). Such impairments result in characteristic patterns of symptoms, error types and performance in various tasks. Differential diagnosis of lexical retrieval impairments can therefore be achieved through error analysis in naming tasks, as well as tasks that assess object knowledge, word comprehension, irregular word reading, and phonological working memory (Table 1). Each pattern of impairment corresponds to a selective deficit in a specific functional component of a cognitive neuropsychological model (Figure 1).

Given the centrality of lexical retrieval deficits in PPA, as well as the centrality of lexical retrieval in communication, it is essential to investigate the specific types of impairment in lexical retrieval and to identify the underlying cognitive deficits. In this investigation, we therefore use the cognitive neuropsychological model to identify the impaired component(s) of the lexical retrieval process for each participant with PPA.

1.1. Stages of lexical retrieval

Figure 1 illustrates a cognitive neuropsychological model of lexical retrieval, which involves multiple stages of cascaded activation. This process begins with the generation of an abstract idea and progresses through successive stages, ultimately leading to the articulation of the intended word. A summary of the characteristic presentation of an impairment in each component is provided in Table 1.

1.1.1. The conceptual system

The first stage of lexical retrieval involves the formation of a conceptual representation based on the speaker’s intended message. This conceptual representation may include

Table 1. Characteristic features of deficit in the different stages of lexical retrieval.

Deficits/ feature	Object knowledge	Word comprehension	Word retrieval	Nonword repetition	Characteristic errors	Explanation within the model
Conceptual system	Impaired	Impaired	Impaired	Spared	Unrelated errors, distant semantic errors, failure to identify object	The correct concept is not activated therefore errors occur across modalities and are not restricted to language. Errors in naming are distant from target.
Semantic lexicon	Spared	Impaired[1]	Impaired	Spared	Semantic errors	The semantic lexicon is shared between production and comprehension and therefore difficulty arises in both. Since the lexicon is organized by meaning, errors are semantic.
Phonological output lexicon	Spared	Spared	Impaired	Spared	Semantic errors (usually negated by the patient), phonological and formal errors, errors in derivational morphology, long hesitations. Surface dyslexia.	Since patients cannot access phonological representations, they sometimes substitute targets for semantically similar words, but can tell that they are wrong since input is intact. Errors can also occur in phonological and derivational-morphological properties of the representations. The phonological lexicon is part of the lexical route necessary for reading irregular and unpredictable words.
Between semantic and phonological lexicons	Spared	Spared	Impaired	Spared	Same as phonological output lexicon but without regularizations in reading	The impairment is in access to the phonological output lexicon from the semantic lexicon, but access through the orthographic input lexicon may still be intact, allowing for reading of irregular and unpredictable words.
Phonological output buffer	Spared	Spared	Impaired	Impaired	Phonological (phonemic) errors, errors in inflectional and derivational morphology	The phonological output buffer assembles words from smaller units such as phonemes and whole morphological affixes therefore if it is impaired these units are involved in omission, substitution, or addition. errors.

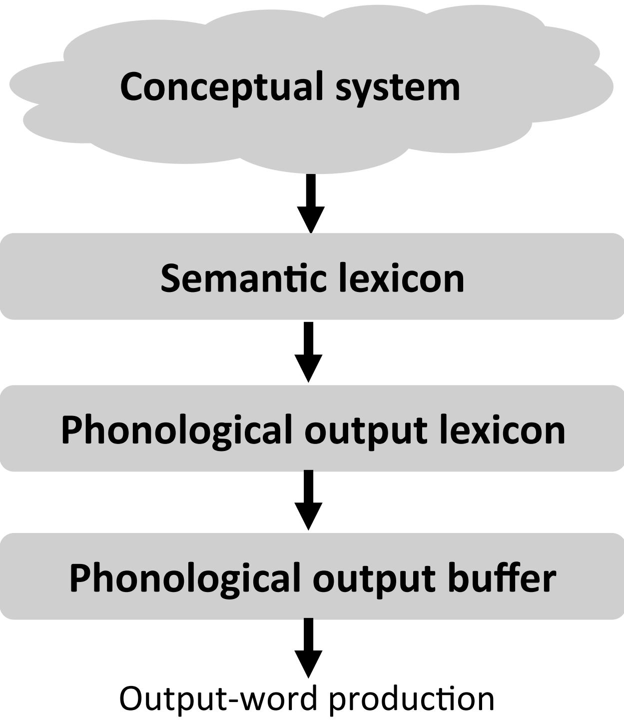

Figure 1. A neuropsychological model of lexical retrieval adapted from Friedmann et al. (2013).

relevant images, intentions, memories, associations, or other pre-linguistic representations. The exact nature of conceptual representations has been widely debated in philosophy and psychology (Fodor, 1998; Frege, 1918/1956; Rips & Medin, 2005; Rosch & Mervis, 1975; Wittgenstein, 1953). The conceptual system, therefore, is a pre-lexical component that is essential for word production, as intention is a prerequisite for linguistic output (Pfau, 2009). The concept serves as the foundation for activating lexical entries in the semantic lexicon. A deficit in the conceptual system is not specific to language, but it has significant implications for language production and comprehension across modalities. Impairments in this component can lead to difficulties understanding objects, and pictures, even in tasks that do not directly involve language production or comprehension, and it also affects the comprehension of words and sentences. In naming tasks, such deficits manifest in the production of words unrelated to the target word or distant semantic errors, and in failure to identify the object correctly in picture naming tasks (Friedmann et al., 2013; Nickels, 1997).

1.1.2. The semantic lexicon

The semantic lexicon is a hub connecting semantically organized entries to corresponding representations in other lexicons, such as phonological representations in the phonological lexicons (input and output) and orthographic representations in the orthographic lexicons (input and output) (Butterworth, 1989). These lexical items are also linked to the non-linguistic conceptual system, either through a one-to-one correspondence between a concept and a lexical item or via a more complex system of semantic features (e.g., J. J. Katz & Fodor, 1963).[2] As a hub, the semantic lexicon is responsible for both input and output processes. Consequently, an impairment in the semantic lexicon manifests itself as difficulty in word comprehension and as semantic errors during naming (e.g., "cat" → "dog") (Howard & Orchard-Lisle, 1984; Nickels, 1995, 1997). Importantly, unlike deficits in the conceptual system, impairments in the semantic lexicon do not affect performance in tasks such as object identification and use, which remain intact (Friedmann et al., 2013; Nickels, 1997).

1.1.3. The phonological output lexicon

The phonological output lexicon stores phonological representations activated by the semantic lexicon. These representations include morphological stems/bases and their compatible affixes (Friedmann et al., 2021). An impairment in the phonological output lexicon manifests as difficulties in naming, including "don't know" responses, prolonged hesitations, semantic errors (where the phonological representation cannot be activated, leading the patient to produce a related word and often reject it, Caramazza & Hillis, 1990), and phonological errors (e.g., *cat* → *cap*, although these constitute a smaller portion of the errors, Gvion & Biran, 2023). Additionally, because the phonological output lexicon stores information about matching derivational morphology affixes, deficits in this lexicon can also lead to errors in derivational morphology (Y. Z. Katz & Friedmann, 2024; Stark, 2020).

Impairments may occur either in the phonological output lexicon itself or in the connection between the semantic lexicon and the phonological lexicon. When the deficit lies within the phonological output lexicon itself, because the phonological output lexicon is part of the lexical route of reading, patients also exhibit regularization errors when reading irregular words or pseudo-homophones aloud, a type of surface dyslexia (Friedmann & Lukov, 2008; Gvion & Friedmann, 2016).

Unlike the semantic lexicon, which supports both comprehension and production, the phonological output lexicon is specific to production. As a result, patients with impairments selective to this lexicon experience production difficulties but no comprehension difficulties.

1.1.4. The phonological output buffer

The phonological output buffer is a short-term memory component. In naming, it is responsible for maintaining and assembling phonological representations retrieved from the phonological output lexicon. It constructs phonological strings from basic units such as phonemes and syllables and maintains the phonological information until articulation is completed. Therefore, impairments in the phonological output buffer lead to phonological (phonemic) errors, including phoneme or syllable omission, substitution, epenthesis, and metathesis (Caramazza et al., 1986; Shallice et al., 2000).

In addition to phonemes and syllables, the phonological output buffer stores pre-assembled morphemes as building blocks for morphologically-complex words. It is also responsible for morphological composition. Therefore, impairment to the phonological output buffer also results in morphological errors in derivational and inflectional morphology, such as the substitution, omission, or addition of affixes (Dotan & Friedmann, 2015).

As a working memory component, the phonological output buffer is sensitive to word length, such that longer words induce more errors in tasks such as reading, repetition, and naming.

When handling nonwords (in repetition or reading), the phonological output buffer receives input from the auditory or orthographic components (phoneme-to-phoneme conversion in repetition, grapheme-to-phoneme conversion in reading, as well as specialized morphological convertors in both modalities), and maintains and assembles these representations into the target nonwords. Real words are present in the lexicons, whereas nonwords are not; therefore, errors are more frequent with nonwords, for which the phonological output buffer does not recieve support from long-term memory (the lexicons). (Dotan & Friedmann, 2015; Friedmann et al., 2013; Shallice et al., 2000).

1.2. Example for word retrieval and possible errors

Consider the retrieval of the word *artichoke* as an example. The process begins with the formation of a conceptual representation in the conceptual system, which may include a mental image of a prototypical artichoke, a memory of an encounter with an artichoke, or related associations. This conceptual representation activates the corresponding entry in the semantic lexicon, which is connected to related entries such as *plant*, *pasta*, and *field*. The semantic entry for *artichoke* then activates the corresponding entry in the phonological lexicon, which contains information necessary for producing the word, such as its phonemes and their order and syllabic structure (e.g., the first phoneme is /a/, the second is /r/, and so on). Finally, the phonological output buffer assembles the word using these phonological instructions (/a/+/r/+/t/+/i/+/ch/+/o/+/k/) and temporarily holds the sounds until they are articulated.

When patients with lexical retrieval deficits name pictures in a picture-naming task, errors may arise at each of these different stages depending on the site of impairment. Patients with a deficit in the conceptual system might produce errors that are unrelated or only distantly related to the target, such as *table* or *cat*. If the impairment is in the semantic lexicon, patients are likely to make semantic errors, such as naming the superordinate category *plant* or *food*, or a semantic neighbor such as *asparagus*. In cases of a deficit in the phonological lexicon, or in the connection between the semantic and phonological lexicons, patients may exhibit long hesitations, report that they "don't know" the word, produce semantic errors they immediately self-correct (e.g., "it's not broccoli"), produce the word in a different language, or make phonological errors. Patients with a deficit in the phonological output buffer will make phonological errors such as *architoke*, and in morphologically complex words, will make morphological errors such as *duckling- > ducker, pavement- > paving*. In Hebrew, a language with rich non-concatenative Semitic morphology, these could be errors in concatenative morphology similarly to English (like adding or omitting the plural suffix, e.g., *tapuz* "orange" ➔ *tapuzim* "oranges"), or in non-concatenative morphology, i.e., substituting the nominal or verbal pattern (e.g., *mafte'ax* "key" ➔ *ptixa* "opening").

1.3. Previous research on lexical retrieval in PPA

Most current research on lexical retrieval in Primary Progressive Aphasia (PPA) is conducted within the framework of the "consensus criteria", which classifies PPA into three distinct variants (Gorno-Tempini et al., 2011). The diagnostic criteria for each variant include, among others, features related to lexical retrieval and access, specifically naming, single-word comprehension, and object knowledge. In the semantic variant (svPPA), impaired confrontation naming and impaired single-word comprehension are core features, with impaired object knowledge as a supporting feature. In the logopenic variant (lvPPA), impaired single-word retrieval is a core feature (with phonological errors as a supporting feature), while spared single-word comprehension and object knowledge serve as supporting features. In the non-fluent agrammatic variant (nfvPPA), apraxia of speech, which may cause phonological errors in naming, was considered a core feature in Gorno-Tempini et al. (2011), while spared single-word comprehension and object knowledge are supporting features. Later, it has become clear that while apraxia of speech can be comorbid with nfvPPA, it is a separate syndrome called "primary progressive apraxia of speech" (Duffy et al., 2021; Josephs et al., 2012). The features related to lexical retrieval and access are summarized in Table 2.

Importantly, viewing these clinical profiles through the lens of cognitive neuropsychological classification reveals that the features related to lexical retrieval in each variant may indicate impairment in one of several different components in the lexical retrieval process. In svPPA, the impairments are consistent with a deficit in the conceptual system if all three features (naming, comprehension, and object knowledge) are impaired, or with a deficit in the semantic lexicon if naming and comprehension are impaired while object knowledge remains intact.[3] In lvPPA, the impairments align with deficits either in the phonological output lexicon, in the connection between the semantic and phonological lexicons, or in the phonological output buffer, all of which cause a deficit in naming with phonological errors and intact comprehension. In nfvPPA, lexical retrieval is typically intact, other than apraxia of speech, which is not a lexical retrieval impairment but can affect naming. Additionally, a syntactic deficit may sometimes appear as a deficit in word retrieval when words appear in inaccessible syntactic positions.

Despite the emphasis on lexical retrieval in the diagnostic framework, few studies have linked PPA symptoms to cognitive models of language. Elizabeth Warrington (1975), one of the pioneers of the neuropsychology of lexical retrieval, examined individuals with

Table 2. Features of PPA variants related to lexical retrieval and their correspondence to impairments in the cognitive neuropsychological model.

Variant/ feature	Naming	Single-word comprehension	Object knowledge	Cognitive neuropsychological model correspondence
svPPA	Impaired (core)	Impaired (core)	Impaired (supporting)	Impairment in conceptual system **or** Impairment in semantic lexicon
lvPPA	Impaired (core) phonological errors (supporting)	spared (supporting)	spared (supporting)	Impairment in phonological output lexicon (or access to it) **or** Impairment in phonological output buffer
nfvPPA	Apraxia of speech (core)	spared (supporting)	spared (supporting)	Spared retrieval (optionally with apraxia of speech)

progressive aphasia and presented a dissociation between object knowledge and word comprehension in Semantic Dementia, indicating the separation between the conceptual system and the semantic lexicon and demonstrating that in fact two separate so-called semantic impairments are possible, one is PPA with a conceptual deficit, the other is PPA with a deficit in the semantic lexicon. Sanches et al. (2018) demonstrated dissociations between semantic information, word form, and grammatical gender in 20 participants (diagnosed with lvPPA or svPPA), using implicit processing and explicit matching tasks. They concluded that these types of information are stored separately in the mental lexicon. A deficit in semantic information would correspond, in cognitive neuropsychological terms, to an impairment in the conceptual system or the semantic lexicon; a deficit in word form would correspond to impairment in the phonological/orthographic input or output lexicons; a deficit in grammatical gender corresponds to impairment in the syntactic lexicon, which stores grammatical gender separately from semantic and phonological information (Biran & Friedmann, 2012).

Several previous studies have shown dissociations between features that are bundled together in the criteria. Mesulam et al. (2013) have shown neural dissociations between errors that stem from impaired object knowledge and those that stem from impaired word comprehension, recognizing two separate networks for lexical-linguistic concepts and object recognition. As for phonological features, used to identify lvPPA, phonological errors do not necessarily stem from working memory impairment (Henderson et al., 2024, 2025), but they may instead result from a deficit in the phonological lexicon. To conclude, previous studies have found dissociations between symptoms that are grouped together in the consensus criteria, however, most of them did not provide an alternative classification theory or criteria for lexical retrieval deficits in PPA, and there are currently no studies that categorize PPA in cognitive neuropsychological terms.

1.4. The present study

In the present study, we propose a classification system for naming deficits in PPA based on a cognitive neuropsychological model of lexical retrieval. An accurate classification of lexical retrieval impairments in PPA may help increase the accuracy of diagnosis and the detailed understanding of the exact difficulties of each patient. . Moreover, describing subtypes of PPA within models of the normal operation of language offers a unique opportunity to study the process of lexical retrieval itself and its relations with other language deficits, such as morpho-syntactic impairments and dyslexia (Gvion & Friedmann, 2016; Y. Z. Katz & Friedmann 2024).

We hypothesize that lexical retrieval and access deficits in progressive aphasia are the same as those previously observed in aphasia due to other etiologies. Therefore, impairments can affect each of the components in the lexical retrieval process and can be described as selective deficits in the cognitive neuropsychological models of naming (Figure 1).

To test this hypothesis, we applied the model to classify 40 Hebrew-speaking patients with PPA, using a comprehensive battery of tasks designed to pinpoint the impaired functional component. Additionally, we conducted error analysis in the naming task, categorizing each error.

While the focus of the study is theoretical and not language-specific, it also contributes novel data by applying this framework to Hebrew-speaking individuals with PPA marking, to our knowledge, the first systematic description of such impairments in Hebrew.

2. Methods

2.1. Participant recruitment

The study followed a prospective, cross-sectional case series design. Participants with PPA were recruited as part of the DIASPORA study (**D**ementia research in **I**sraelis of **A**dverse **S**ocial health determinants and **P**opulations **O**f underrepresented **A**ncestry) , conducted at the Rabin Medical Center, Israel. The inclusion criteria for the DIASPORA study included age between 40 and 80 years, newly emerging cognitive decline that impaired daily activities or independence, and a comprehensive diagnostic evaluation to exclude non-neurodegenerative causes. The evaluation included recent brain imaging (CT or MRI) and laboratory tests including complete blood count, blood chemistry, thyroid-stimulating hormone levels, and vitamin B-12 levels. Three additional participants who were not enrolled in the DIASPORA study were independently assessed after being referred to the Language and Brain Lab at Tel Aviv University for reading and language evaluations. Following a comprehensive neurocognitive assessment, brief cognitive testing, and brain neuroimaging, they were diagnosed with PPA. Their medical records were subsequently reviewed in a consensus meeting by two experienced behavioral neurologists. Demographic details for all participants are provided in Table 3.

2.2. Diagnosis of PPA clinical syndrome

Aphasia was identified based on the results of comprehensive language assessment and spontaneous speech analysis, conducted by two researchers specializing in aphasia and language disorders (Y.Z.K and N.F) including tests examining reading, syntactic production and comprehension, and phonological working memory.

The diagnosis was further supported by two experienced behavioral neurologists (O.K and A.G), who evaluated participants through informant interviews, standardized caregiver questionnaires, neurological examinations, and neuropsychological testing. The neuropsychological assessment included the Montreal Cognitive Assessment (MoCA) (Nasreddine et al., 2005), and tests of verbal memory, executive functions, and visuospatial skills. Functional decline in independence and instrumental activities of daily living (I-ADL) was evaluated using the Functional Activities Questionnaire (FAQ) (Pfeffer et al., 1982) and the Clinical Dementia Rating (CDR), supplemented by the CDR FTLD language subscale (CDR-Language) (Knopman et al., 2008).

Fifty participants were initially included according to the core diagnostic criteria for PPA, however 10 were later excluded due to questionable language impairment, as indicated by a CDR-Language score of 0.5. The final cohort consisted of 40 participants who were diagnosed with PPA based on a neurological examination that indicated that language impairment was the most prominent symptom.

Brain MRI scans were first evaluated independently and then reviewed in a consensus meeting by two experienced neurologists (O.K. and A.G.). To assess brain atrophy, the Harper

Table 3. Demographic and cognitive information on participants.

Patient	Sex	Age[a]	Time since onset[a]	Loss of independence and severity[b]	CDR Language[c]	MoCA	Regional grey matter atrophy[d]
1	F	60	0.8	Moderate	1	11	Frontoinsular
2	F	60	2	Moderate	2	16	Frontoinsular
3	M	67	1.7	Mild	1	N/A	Parietal, Frontoinsular
4	F	63	7.7	Mild	1	22	Anterior Temporal
5	F	83	0.5	Mild	1	18	Frontoinsular, Temporal, Parietal
6	F	77	4	Severe	N/A	20	Anterior Temporal, Parietal, Frontoinsular
7	F	73	2	Moderate	1	17	Parietal, Frontoinsular
8	F	72	2	Moderate	2	11	No Atrophy
9	F	64	3	Moderate	2	10	Parietal, Frontoinsular
10	F	73	3	Moderate	1	N/A	Anterior Temporal
11	M	59	2	Mild	1	19	Parietal, Frontoinsular
12	M	72	2	Moderate	2	4	Parietal, Frontoinsular
13	F	59	2	Mild	1	17	No Atrophy
14	M	65	2.3	Moderate	1	15	Parietal, Frontoinsular
15	M	48	5	Moderate	2	13	No Atrophy
16	M	66	2	Mild	1	13	No Atrophy
17	M	59	1	Mild	1	21	Right Parietal (Left Handed)
18	M	64	4.5	Severe	1	9	Frontoinsular
19	M	55	3	Severe	2	11	N/A
20	F	58	0.7	Mild	2	17	Frontoinsular
21	F	61	3	Severe	2	N/A	No Atrophy
22	M	79	3	Mild	1	11	Frontoinsular
23	F	62	3	Mild	1	16	No Atrophy
24	F	75	1	Mild	1	10	Frontoinsular
25	M	55	2	Mild	1	21	Anterior Temporal
26	M	79	4	Mild	1	13	Posterior Perisylvian/Parietal
27	F	66	2	Mild	1	15	Posterior Perisylvian/Parietal, Frontoinsular
28	M	70	2	Mild	1	16	Posterior Perisylvian/Parietal, Frontoinsular
29	M	78	2	Severe	1	14	Anterior Temporal
30	F	56	5	Moderate	2	8	Anterior Temporal, Parietal, Frontoinsular
31	M	65	0.3	Moderate	1	17	Parietal, Frontoinsular
32	F	67	5.5	Mild	2	27	Parietal, Frontoinsular
33[e]	F	69	4	Mild	1	14	No Atrophy
34	M	65	1	Severe	N/A	N/A	Frontoinsular, Anterior Temporal
35	M	75	2	Mild	1	N/A	No Atrophy
36	F	66	6	Mild	1	24	Parietal
37	M	53	2	Mild	1	19	No Atrophy
38	F	77	5	Mild	2	15	Frontoinsular
39	M	54	0.5	Mild	1	23	No Atrophy
40	F	65	2.5	Moderate	2	16	Frontoinsular

Abbreviations: CDR - Clinical Dementia Rating, MoCA - Montreal Cognitive Assessment, F - Female, *M* - Male, N/A - not available. [a]In years, at assessment [b]Severity of decline in independence on Instrumental activities of daily living (IADL), as derived from global CDR and FAQ, and summarized as Mild - Independent or with subjective difficulties performing IADL. Moderate - Requires assistance or supervision on IADL. Severe - Is dependent on other for most IADL. [c]CDR language impairment levels: 0 = None, 0.5 = Questionable, 1 = Mild, 2 = Moderate, 3 = Severe [d]Regions are left hemisphere unless noted otherwise. [e]Participant 33 was tested in both English, her first language, and Hebrew, the language she spoke for over 50 years.

brain atrophy visual rating scale was applied to each scan. This scale provides a semi-quantitative measure of atrophy across 12 brain regions (six per hemisphere), with scores ranging from 0 to 3 for the frontal, insular, and parietal regions, and from 0 to 4 for the anterior and medial temporal regions. The Harper scale has been extensively validated for assessing neurodegenerative conditions and clinical syndromes, including FTD and PPA. Regional atrophy was classified as positive if the score was ≥ 2 in the anterior insular and parietal regions or ≥ 3 in the anterior temporal regions. Additionally, significant atrophy in the inferior frontal gyrus was also considered positive.

2.3. Comprehensive assessment of lexical retrieval and access

All participants underwent a picture-naming task (SHEMESH, Biran & Friedmann, 2004), which includes 100 color images corresponding to Hebrew words that vary in morphological complexity, phonological complexity, conceptual category, grammatical gender, and frequency. Performance on each task was compared against normative data from the Language and Brain Lab at Tel Aviv University.

To assess for conceptual abilities and object knowledge, we employed a 37-item picture association task (MA KASHUR pictures, Biran & Friedmann, 2007). In this task, participants were asked to associate a picture at the top of the page with one of two pictures at the bottom: one conceptually related and the other a distractor.

For single-word comprehension, we used a 20-item word-picture matching task with (PILPEL, Friedmann, 2015). In this task, participants heard a word and were asked to select the corresponding picture from a set of eight options, the target picture and seven semantic distractors.

To test for surface dyslexia, participants completed a dyslexia screening norm-referenced battery of reading words and nonwords designed to detect various types of dyslexia, including surface dyslexia (TILTAN, Friedmann & Gvion, 2003).

Phonological working memory was assessed using a nonword repetition task (BLIP, Friedmann, 2003).

Differential diagnosis of types of lexical retrieval impairment was done first through tasks listed in this section, which test directly the different components of the lexical retrieval process: conceptual (object knowledge – picture association), semantic (word-comprehension – word-picture matching), and phonological output (nonword repetition). Then, this diagnosis is complemented by a thorough error analysis in the naming task. The diagnosis of a deficit in each component was determined when the performance of the patient in the task that directly assesses this component was significantly below the norm, and at least one error in naming characteristic of the impaired component. When patients did not complete the relevant direct task, we used a Crawford and Howell's (1998) t-test comparison for the relevant error type to determine an impairment.

For the phonological output lexicon and the connection between the semantic and phonological lexicons, the direct-assessing task was the naming task itself. Therefore, because we had only one measure, we were more conservative, and the threshold was set at more than three errors (3 was the maximal number of characteristic phonological output lexicon errors for the participants with PPA who had intact lexical retrieval).[4]

Phonological errors and derivational morphology errors are indicative of both a phonological output buffer impairment and phonological output lexicon impairment. Therefore, for patients who made phonological/morphological errors in naming, a combined impairment in both components was determined only if the patient met the unique criteria for each of the components: impaired nonword repetition for a diagnosis of phonological output buffer impairment, and more than three characteristic phonological output lexicon errors in naming, at least one of which was not a phonological or a morphological error, but an error type unique to the phonological output lexicon.

Participant #5 was not tested with word-picture matching, but instead was tested with a spoken word association task to assess the semantic lexicon. Participant #8 was not tested with the nonword repetition task, but instead she was tested in serial word recall task, which was intact (serial recall span = 4.5 words).

While each type of impairment is associated with a characteristic performance pattern (see Table 1), it is crucial to consider that in practice, patients often present with multiple impairments (e.g., deficits in both the conceptual system and the phonological output buffer). Multiple impairments are diagnosed when the error pattern reflects deficits in more than one component (e.g., a deficit in the conceptual system and the phonological output buffer will result in impairment both in picture association and in nonword repetition).

However, in some cases, multiple impairments are indistinguishable from a single impairment. A deficit in the conceptual system is indistinguishable from a combined deficit in the conceptual system and the semantic lexicon, as the symptoms of a semantic lexicon deficit are a proper subset of those of a conceptual system deficit. For a similar reason, a deficit in the phonological output lexicon is indistinguishable from a combined deficit in the phonological output lexicon and the connection between the semantic and phonological lexicons. In such cases, the more parsimonious diagnosis assumes a single impairment. These diagnostic considerations are visually represented in the decision tree shown in Figure 2, which outlines the algorithm used to diagnose participants in the current study.

2.4. Data analysis

Performance on each task was compared to task norms. These norms were previously derived by defining an impairment threshold using a t-test for case-control comparison with an alpha level of 0.05 (Crawford & Garthwaite, 2002; Crawford & Howell, 1998). This method allows for a more sensitive detection of impairments compared to using a fixed z-score threshold, as it takes into account the size of the normative sample. In two tests (word-picture matching and picture association), the normative group performed at ceiling (above 99 or with SD = 0). In order to avoid over-diagnosis in these cases, more than one error was considered an impaired performance.[5]

3. Results

Of the 40 participants, 30 participants (75%) were found to have impaired lexical retrieval, whereas 10 participants (25%) had spared lexical retrieval. No relation was found between the presence of lexical retrieval impairment and age ($r_{pb} = 0.09$, $p = .56$), sex (χ^2 (1, $N = 40$) = 0.03, $p = .85$), or time since aphasia started ($r_{pb} = 0.09$, $p = .60$). Of the participants with impaired lexical retrieval, 13 had an impairment in a single cognitive component, 9 had an impairment in two components, and 8 had an impairment in three components. There is a significant weak correlation between time since symptoms' onset and number of impaired components when considering only patients who have a lexical retrieval impairment (Spearman $r = 0.37$, $p = .046$). The correlation is not significant when including patients with intact lexical retrieval, i.e., 0 impaired components (Spearman $r = 0.28$, $p = .08$).

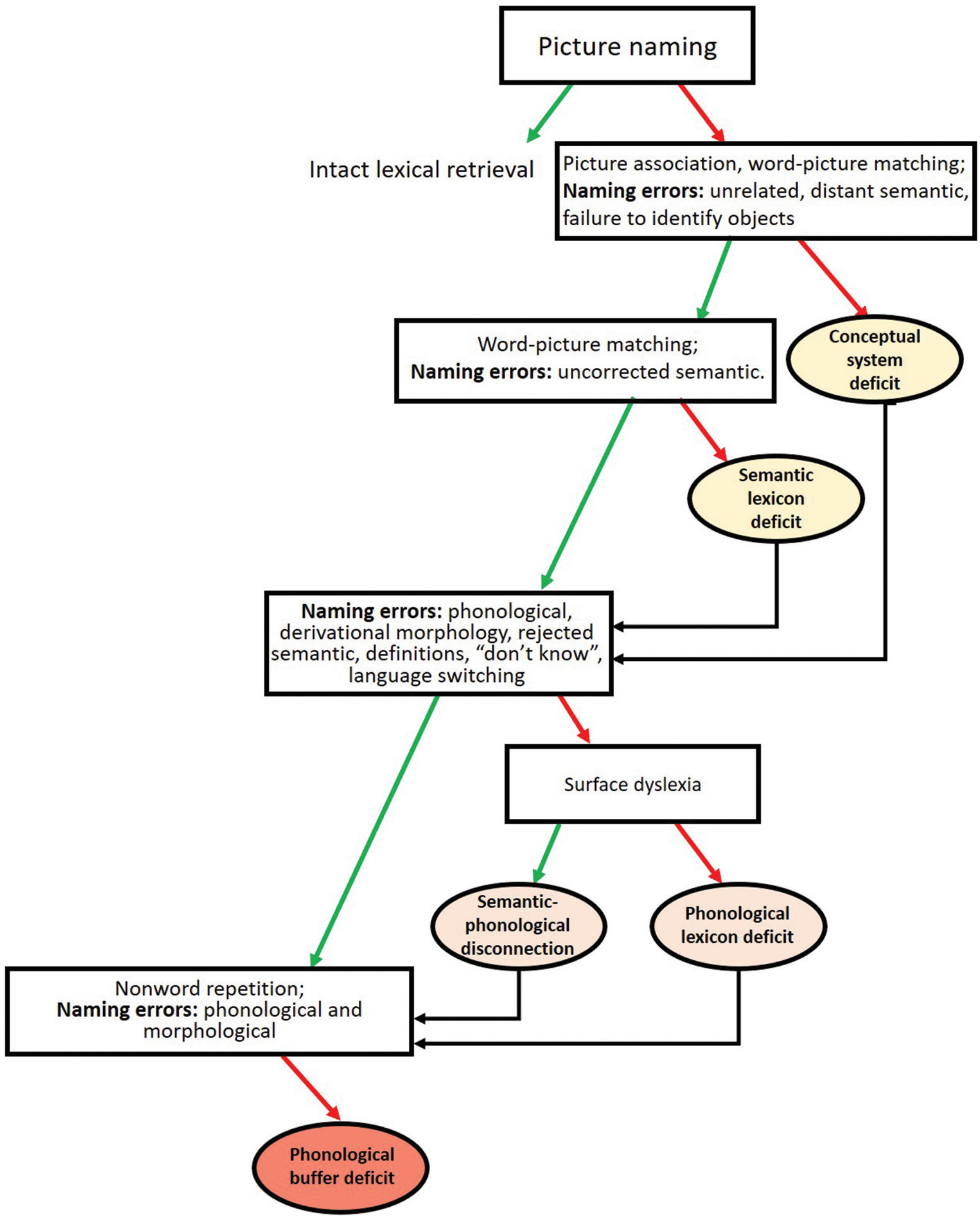

Figure 2. An algorithm for determining the functional impairment in lexical retrieval. **Green arrows** indicate performance within the norm in the tasks and no higher rate of the relevant error types than the normative threshold. **Red arrows** indicate impaired performance in the tasks and errors of the relevant types.

The impaired loci were as follows: 5 participants had a deficit in the conceptual system, 13 had impairment in the semantic lexicon, 18 had deficits related to the phonological output lexicon- in the lexicon itself or in the access to it, and 19 demonstrated impairments in the phonological output buffer.

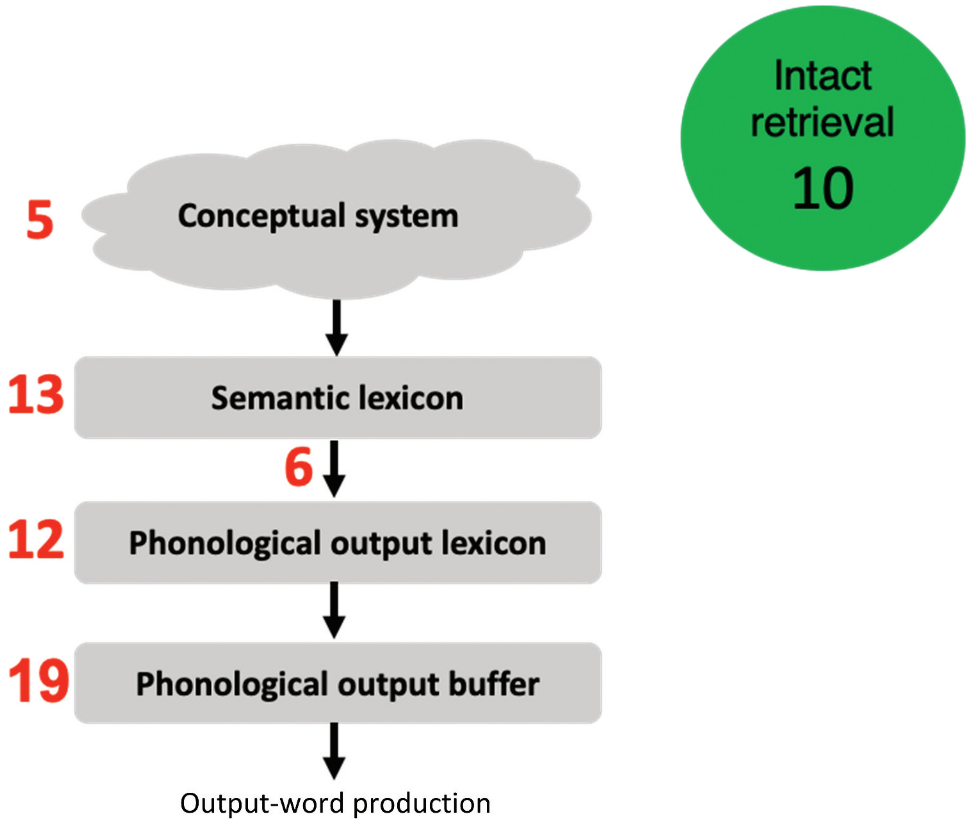

Figure 3. Number of participants with impairment in each of the model's components.

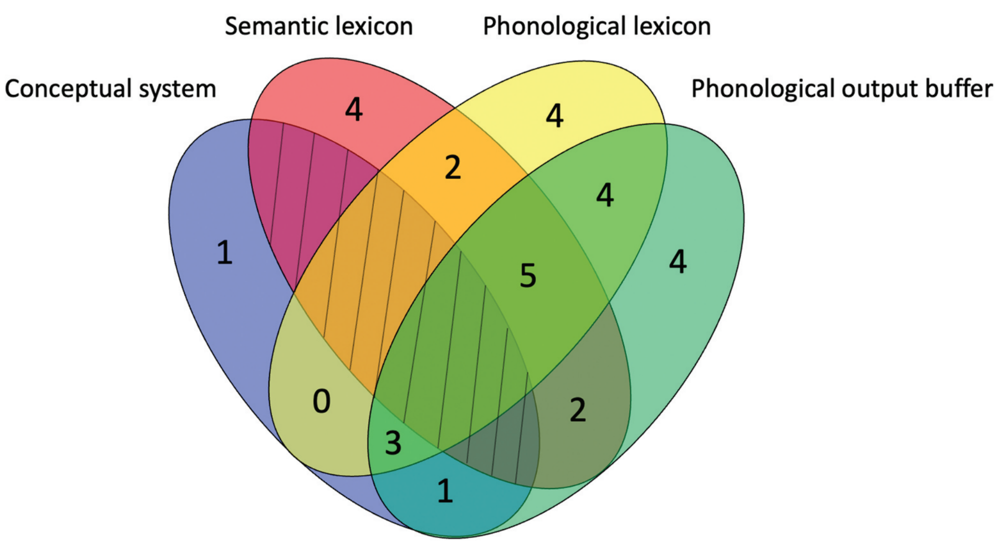

Figure 4. Number of participants with impairment in each cognitive component or combination of components. Recall, that our tasks currently do not allow us to distinguish between a conceptual impairment and a double impairment in the conceptual system and in the semantic lexicon and therefore the intersection of conceptual&semantic deficit appears dashed in the figure. (participants with impairments in the connection between the semantic and phonological lexicons, as well as those whose impairment could not be determined to lie specifically in the phonological output lexicon or in the disconnection itself, are all grouped under phonological output lexicon impairment).

Table 4. Participants' functional locus/loci of impairment.

Participant	Functional locus/loci of impairment
1	Semantic lexicon
2	Semantic lexicon, Phonological output lexicon, Phonological output buffer
3	Semantic lexicon, Phonological output lexicon
4	Semantic lexicon, Phonological output lexicon, Phonological output buffer
5	Semantic lexicon
6	Semantic lexicon, Phonological output lexicon/disconnection, Phonological output buffer
7	Intact
8	Semantic lexicon, Phonological output lexicon/disconnection, Phonological output buffer
9	Conceptual system, Phonological output lexicon, Phonological output buffer
10	Phonological output lexicon, Phonological output buffer
11	Phonological output buffer
12	Conceptual system, disconnection, phonological output buffer
13	Phonological output buffer
14	Semantic lexicon, Phonological output lexicon, Phonological output buffer
15	Semantic lexicon, Phonological output buffer
16	Intact
17	Semantic lexicon, Phonological output buffer
18	Phonological output lexicon, Phonological output buffer
19	Conceptual system, Phonological output lexicon, Phonological output buffer
20	Semantic lexicon
21	Intact
22	Phonological output lexicon, Phonological output buffer
23	Phonological output lexicon, Phonological output buffer
24	Phonological output buffer
25	Phonological output lexicon
26	Semantic lexicon
27	Phonological output lexicon
28	Disconnection
29	Conceptual system, Phonological output buffer
30	Conceptual system
31	Intact
32	Phonological output buffer
33	Semantic lexicon, disconnection
34	Intact
35	Phonological output lexicon/disconnection
36	Intact
37	Intact
38	Intact
39	Intact
40	Intact

The number of participants with impairment in each cognitive component is summarized in Figure 3. Figure 4 is a visualization of the intersection between the impairments. Table 4 summarizes the impairments for each participant.

3.1. Spared lexical retrieval

Participants whose performance in picture naming was similar to age-matched norms were categorized as having spared lexical retrieval. Their performance in the lexical retrieval tasks is presented in Table 5.

Focusing on these participant's performance in additional tasks, participants with intact naming also had intact word comprehension and object knowledge (picture association). Four participants have surface dyslexia even though their naming is intact. This is not surprising, since surface dyslexia is not necessarily due to impairment in the components involved in lexical retrieval. Although surface dyslexia can

Table 5. Participants with spared lexical retrieval and their task performance.

Participant	Picture naming	Picture association	Word comprehension	Surface dyslexia	Nonword repetition
7	95%	N/A	N/A	yes	85%
16	95%	N/A	100%	Yes	77%
21	90%	92%	95%	Yes	56%
31	93%	100%	95%	Yes	50%
34	93%	N/A	N/A	No	N/A
36	95%	97%	100%	No	73%
37	93%	100%	100%	No	88%
38	90%	100%	100%	No	56%
39	100%	100%	100%	No	90%
40	95%	100%	100%	No	71%

Impairment threshold for picture naming in this task: Age 50–60: 93%, age 60–70: 90%, age 70–80: 89%, age 80–85: 80%. N/A: the test was not administered to this patient. Shaded cells indicate impaired performance.

result from an impairment in the phonological output lexicon, which also partakes in naming, it can also be caused by impairment to the orthographic lexicon or the connection between the orthographic lexicon and the phonological output lexicon, both of which participate in reading irregular words, but not in lexical retrieval (Coltheart & Funnell, 1987; Friedmann & Lukov, 2008; Gvion & Friedmann, 2016). Seven participants (#7, #16, #21, #31, #36, #38, #40) had impaired or marginally impaired phonological working memory as evidenced by their performance in nonword repetition and serial recall span. This shows that a phonological output buffer impairment does not necessarily cause phonological errors in naming. When the rest of the components in the process are intact, specifically the phonological output lexicon, the lexical components (which are long term memory stores) support the activation of the phonemes in the buffer, reducing the load on working memory in naming. In milder cases of phonological output buffer impairment this may be enough not to demonstrate phonological errors in picture naming. Therefore, in these cases, retrieving single words is not necessarily susceptible to errors, especially when the words are not particularly long or phonologically- or morphologically complex. In some cases, like the ones presented here, phonological output buffer impairment mainly affects nonwords, or lists of real words.

3.2. Conceptual impairments

Six participants had a conceptual system impairment, identified by impaired picture association and word-picture matching in addition to at least one characteristic error (unrelated substitutions, distant semantic errors, or failure to identify the object in the picture).[6] Participants with a conceptual impairment and their task performance are presented in Table 6. The number of errors in the naming task that are characteristic to a conceptual system deficit appear in the rightmost column of Table 6, “Conceptual system errors”.

Examples for naming errors that our participants with a conceptual deficit produced are presented in (1) - (2).

(1) **Unrelated substitution** (participant #12): seashells ➔ *cups*
(2) **Response indicating failure to identify object** (participant #30): vase ➔ *I don’t know what it is. I don’t always recognize things.*

Table 6. Participants with conceptual system impairment and their task performance.

Participant	Picture naming	Picture association	Word comprehension	Surface dyslexia	Nonword repetition	Conceptual system errors
9	58%	76%	80%	Yes	63%	1
12	0%	33%	31%	No	N/A	4
19	0%	74%	85%	Yes	23%	3
29	81%	84%	90%	Yes	54%	1
30	0%	59%	13%	Yes	92%	6

N/A: the test was not administered to this patient. Shaded cells indicate impaired performance.

Surface dyslexia was dissociated from conceptual impairment (participant #12 did not have surface dyslexia).

We found a moderately positive correlation between picture association score and MoCa scores across all patients ($r\ (25) = .05$, $p = .002$). This is expected since a conceptual impairment is not confined to naming or even language, but is a general cognitive impairment. There is also a weak correlation between picture naming and MoCa scores ($r(33) = .34$, $p = .044$), which might be partly due to the naming component of the MoCa test.

To ascertain that the deficit was indeed a conceptual deficit rather than visual agnosia, we examined the patients' sentence-level performance when no visual input was involved. In unstructured conversation before and during the language assessment, all five participants showed significant difficulties in understanding everyday conversation and following instructions, all of which did not require any visual input. In a syntactic production task that did not involve images, all patients had severe difficulties. Three of them (9, 12, 19) were unable to perform the task at all, suggesting difficulty in understanding or following instructions, consistent with a conceptual impairment and not with visual agnosia. The other two (29, 30) struggled to produce any sentences, whether canonical or non-canonical. A general difficulty in production regardless of sentence type is consistent with a conceptual impairment that may affect the organization of the message in production. Importantly, the patients showed these difficulties without any visual input, which rules out visual agnosia as the origin of the deficit.

3.3. Semantic lexicon impairment

Thirteen participants had impaired semantic lexicon. Seven patients were identified as having impaired semantic lexicon on the basis of their impaired single word comprehension and at least one semantic error in naming which was not self-corrected. Six other patients, who did not undergo a word comprehension task, were identified with a semantic lexicon deficit by their errors in naming: these patients made at least four uncorrected semantic errors. Patients with a semantic lexicon impairment are presented in Table 7.

Examples for naming errors that our participants with a deficit in the semantic lexicon produced are presented in (3)-(4).

(1) **Semantic error, semantic neighbor** (participant #1): truck ➔ *car, bus*
(2) **Semantic error, superordinate** (participant #5): owl ➔ *it's a bird*

Table 7. Participants with a semantic lexicon impairment.

Participant	Picture naming	Picture association	Word comprehension	Surface dyslexia	Nonword repetition	Semantic errors
1	74%	N/A	N/A	No	N/A	8
2	84%	N/A	N/A	Yes	63%	5
3	76%	100%	N/A	Yes	96%	5
4	29%	97%	55%	Yes	83%	1
5	55%	N/A	0%	N/A	N/A	1
6	29%	86%	N/A	N/A	0%	5
8	67%	100%	N/A	N/A	N/A	5
14	76%	92%	90%	Yes	85%	9
15	81%	100%	90%	Yes	50%	10
17	87%	97%	90%	Yes	75%	3
20	87%	100%	90%	No	53%	10
26	80%	95%	85%	No	73%	6
33	39%	N/A	N/A	No	N/A	4

N/A: the test was not administered to this patient. Shaded cells indicate impaired performance.

Interestingly, a dissociation was found between a semantic deficit and surface dyslexia: four of the participants who had a semantic lexicon impairment had no surface dyslexia (#1, #20, #26, #33).

3.4. Phonological output lexicon impairment and impairment to connection between semantic and phonological lexicons

Eighteen participants have an impairment in the phonological lexicon or in the connection between the semantic and the phonological lexicons, as they made more than three characteristic errors (self-corrected semantic errors, phonological error, formal error, error in derivational morphology, and language switching). The participants were further categorized as having impairment in the phonological lexicon itself (12 patients who also had surface dyslexia – made regularization errors in reading) and those with a deficit in the connection between the semantic and the phonological lexicons (3 patients without surface dyslexia). Three additional patients were not tested for surface dyslexia, so we could not determine if their phonological-lexicon-related deficit was in the lexicon itself or in the access to it (these patients are presented in Figure 1 together with the patients with a deficit in the connection between the lexicons). Task performance of the participants with a deficit in the phonological output lexicon or in the access to it from the semantic lexicon is summarized in Table 8.

Examples for naming errors that our participants with a deficit in the phonological output lexicon produced are presented in (5)-(6).

(1) **Derivational morphology error** (participant #6): maclema (camera) ➔ *calmania* (photo studio)
(2) **Self-corrected/negated semantic substitution** (participant #27): jar ➔ *it's not a bottle*

Table 8. Participants with a phonological lexicon or a deficit in the access to it from the semantic lexicon.

Locus of phonological deficit	Participant	Picture naming	Picture association	Word comprehension	Surface dyslexia	Nonword repetition	Phonological lexicon errors
Phonological lexicon	2	84%	N/A	N/A	Yes	63%	7
	3	76%	100%	N/A	Yes	96%	5
	4	29%	97%	55%	Yes	83%	5
	9	58%	76%	80%	Yes	63%	5
	10	55%	N/A	94%	Yes	27%	12
	14	76%	92%	90%	Yes	85%	13
	18	78%	95%	100%	Yes	75%	5
	19	0%	74%	85%	Yes	23%	6
	22	53%	95%	95%	Yes	81%	17
	23	13%	100%	100%	Yes	83%	6
	25	24%	97%	95%	Yes	94%	8
	27	75%	100%	100%	Yes	90%	13
Semantic-phonological lexicon disconnection	12	0%	33%	31%	No	N/A	5
	28	60%	87%	100%	No	N/A	11
	33	39%	N/A	NA	No	N/A	8
Undetermined	6	29%	N/A	N/A	N/A	0%	5
	8	67%	100%	N/A	N/A	N/A	22
	35	85%	N/A	N/A	N/A	88%	7

N/A: the test was not administered to this patient. Shaded cells indicate impaired performance.

3.5. *Phonological output buffer impairment*

Nineteen participants had impairment in the phonological output buffer as they had impaired nonword repetition (< 88%) and made at least one characteristic phonological output lexicon errors (phonological errors or morphological errors in derivational or inflectional morphology). Their performance is presented in Table 9.

Examples for naming errors that our participants with a deficit in the phonological output buffer produced are presented in (7)-(8).

(1) **Phonological error, syllable deletion** (participant #2): xacocra (trumpet) ➔ *cocra* (nonexistent word)
(2) **Inflectional morphology error** (participant #8) xacil (eggplant) ➔ *xacil-im* (eggplants)

To ascertain that the deficit was indeed a phonological output buffer deficit rather than apraxia of speech, we examined what kind of errors the patients made in morphological affixes: whether they made phonemic substitutions (characteristic of apraxia of speech) or whole unit substitutions of the whole morpheme (characteristic of a phonological output buffer impairment) (Gvion et al., 2021). All of the participants made whole unit morphological errors in naming or reading, and none of them made phonemic errors within affixes, indicating a deficit in the phonological output buffer rather than apraxia of speech.

Table 9. Participants with phonological output buffer impairment.

Participant	Picture naming	Picture association	Word comprehension	Surface dyslexia	Nonword repetition	POB errors
2	84%	N/A	N/A	Yes	63%	5
4	29%	97%	55%	Yes	83%	1
6	29%	N/A	N/A	N/A	0%	2
8	67%	100%	N/A	N/A	N/A	8
9	58%	76%	80%	Yes	27%	3
10	55%	N/A	94%	Yes	27%	10
11	87%	N/A	100%	No	75%	5
12	0%	33%	31%	No	N/A	3
13	83%	95%	100%	Yes	60%	3
14	76%	92%	90%	Yes	85%	5
15	81%	100%	90%	Yes	50%	3
17	87%	97%	90%	Yes	75%	4
18	78%	95%	100%	Yes	75%	3
19	0%	74%	85%	Yes	23%	4
22	53%	95%	95%	Yes	81%	4
23	13%	100%	100%	Yes	83%	1
24	15%	97%	100%	Yes	31%	1
29	81%	84%	90%	Yes	54%	1
32	55%	100%	95%	No	60%	1

N/A: the test was not administered to this patient. Shaded cells indicate impaired performance.
POB = Phonological Output Buffer.

4. Discussion

The goal of this study was to describe the range of lexical retrieval impairments present in individuals with PPA as impairments in the cognitive neuropsychological process of lexical retrieval. We aimed to the specific functional locus (or loci) of each participant's impairment based on a detailed assessment of their performance and error types in a battery of production and comprehension tasks.

4.1. Main findings

For this purpose, 40 Hebrew-speaking participants with PPA were assessed for lexical retrieval impairments. Of these, 30 participants (75%) exhibited lexical retrieval deficits, while 10 participants (25%) demonstrated spared lexical retrieval abilities.

Among the participants with impairments, 5 had a deficit in the conceptual system, 13 exhibited impairment in the semantic lexicon, 18 showed deficits in the phonological output lexicon or the connection between the semantic and phonological lexicons, and 19 demonstrated impairments in the phonological output buffer. Of the 30 participants with a lexical retrieval and access impairment, 13 participants had deficits in a single cognitive component, 9 exhibited impairments in two components, and 8 had impairments in three components.

The high prevalence of lexical retrieval impairments observed in this study aligns with previous research identifying word-finding difficulties as a hallmark feature of PPA (Mesulam et al., 2012; Rohrer et al., 2008). One should also notice that lexical difficulties are easily discernible in everyday conversations, by the patients and by their interlocutors. As a result, individuals with lexical deficits are more likely than other language deficits to approach clinics and get diagnosed with PPA, hence the relatively high rate of lexical difficulties in patients diagnosed with PPA.

4.2. A fine-grained classification of lexical retrieval impairments in PPA

As we hypothesized, impairments were identified in each stage of the lexical retrieval model, with each impairment presenting a distinct and defined error pattern in both the naming task and the additional assessments. Using the tasks and error analysis we found five different types of naming disorders: we identified PPA patients with a selective impairment in the conceptual system, the semantic lexicon, the phonological output lexicon, the connection from the semantic lexicon to the phonological output lexicon, and in the phonological output buffer.

Of all the patients in the current study, those who exhibited difficulties in tasks designed to assess a specific component also produced the characteristic error types associated with that impaired component. Patients with a conceptual system impairment experience difficulties in object knowledge, as seen in the picture association task and the word-picture matching task. In naming, they produce errors such as semantically distant substitutions, unrelated errors, and failure to identify objects, reflecting difficulty in object identification. Patients with a semantic lexicon impairment are able to identify objects but have difficulty understanding and producing words, as demonstrated in word-picture matching tasks. In naming, they consistently produce semantic errors, indicating problems accessing the appropriate lexical representation. Individuals with a phonological output lexicon impairment, when no additional deficits are present, do not exhibit comprehension difficulties. However, they struggle with naming and produce characteristic errors such as "don't know" responses, long hesitations, self-corrected semantic errors, and phonological or formal errors, consistent with an inability to fully retrieve phonological representations. Patients with a phonological output buffer impairment have difficulty with nonword repetition, a task that relies on phonological working memory. In naming, they produce phonological errors mainly in long and phonologically complex words and morphological errors affecting both derivational and inflectional morphology, reflecting the role of the phonological buffer in assembling and maintaining phonological structures. Finally, patients with intact lexical retrieval measured by intact picture naming also have intact word comprehension and object knowledge if input components are also intact.

The classification method used in this study is based on a cognitive model of the flow of information in non-impaired language, and as such it does not merely describe, but also explains the attested patterns of impairment. These same impairments and their organization in a neuropsychological model are well studied in other neurological conditions such as post-stroke aphasia and developmental disorders (Friedmann et al., 2013; Howard & Gatehouse, 2006; Nickels, 1995, 1997). In these populations, the same rationale and principles we apply here for the classification and diagnosis of specific loci of impairments were applied, the different impairment were defined on the basis of the word processing models, and specific types of lexical impairment were identified. These studies used the cognitive neuropsychological logic of impairments at different stages of the lexical retrieval system to classify language impairments.

Using a model-based classification also allows for a higher resolution of diagnosis in comparison to the tripartite classification into variants: The diagnostic criteria for svPPA encompass patients with impaired naming and word-comprehension, regardless of whether they present with impaired object knowledge as well. Therefore, it encompasses impairment to two different cognitive components, the conceptual system, a general, non-linguistic, cognitive component, and the semantic lexicon which is a linguistic lexical component. These two impairments have different behavioral manifestations and also different neural underpinnings (Mesulam et al., 2013). Similarly, the diagnostic criteria for lvPPA encompass patients with impairments in one of three different cognitive loci: the phonological output lexicon, access to the phonological output lexicon from the semantic lexicon, and the phonological output buffer. All of these cause naming deficits with phonological errors without a deficit in comprehension and may affect repetition of words and sentences. A deficit in the phonological output lexicon also causes surface dyslexia, another supporting criterion of lvPPA.

Additionally, the finding that a single patient may have an impairment in more than one cognitive component, possibly due to broader atrophy, is better described using a componential approach rather than a syndrome-based classification. This is especially the case given that the consensus criteria are designed to exclude mixed diagnosis with more than one variant, as the criteria for each variant list exclusion criteria with symptoms of the other variants. This causes a problematic situation given the progressive nature of PPA, where patients who have a broader impairment have a lesser chance of being classified. Thus, using a model-based classification algorithm can better diagnose the nature of lexical retrieval deficit and allow for the description of multiple impairments.

4.3. Suggestions for future refinements

Even though the tasks and the method of classification we used in the current study can uncover patients' impairments in a relatively high resolution, there are still unaddressed impairments, which are not directly related to lexical retrieval but can affect task performance and disguise as lexical retrieval impairments: visual agnosia and apraxia of speech.

Visual agnosia might be erroneously diagnosed as conceptual system impairments. When tasks involve a visual stimulus (e.g., picture naming, word-picture matching, and picture association), they involve visual analysis of the input and its mapping into a conceptual representation. Therefore, visual agnosia, although not a form of aphasia, can cause errors that are similar to errors produced by patients with a conceptual deficit in tasks with pictures. Since visual impairments pertain specifically to visual stimuli while conceptual impairments also affect other modalities, to adjudicate between the two, studies should include tasks that do not involve visual input, such as naming to definition and word association. In the current study we relied on participants' difficulties in sentence production (with no visual input) and auditory comprehension in spontaneous speech and structured tasks as evidence supporting a conceptual deficit rather than visual agnosia.

Finally, apraxia of speech might be confused with a phonological output buffer impairment. The difference between the two is that while apraxia of speech causes phonemic errors, a phonological output buffer impairment also causes substitutions to larger linguistic units such as morphemes, number words, function words, and sentences (Dotan & Friedmann, 2015; Gvion et al., 2021). In the current study, we relied on the fact that participants made whole unit morphological errors rather than phonemic errors within affixes to detemine that their impairment was indeed in the phonological output buffer.

4.4. Conclusion

In summary, this study highlights the importance of a precise procedure for classifying lexical retrieval impairments in PPA, based on a theory of language, a variety of tasks, and error analysis. Such a procedure allows for accurate diagnosis, which in turn provides a clear understanding of the specific deficits each patient faces. This enables the development of tailored communication strategies and intervention plans to address patients' unique needs. For example, distinguishing between conceptual and semantic impairments can help determine whether non-linguistic models of communication are expected to be helpful; distinguishing between semantic and phonological impairments clarifies whether the deficit affects both production and comprehension (in which case communication with the patient should be adapted) or is restricted to production alone; differentiating between impairments in the phonological output buffer and the phonological output lexicon informs whether the difficulty lies in long-term memory for phonological forms or in phonological working memory (in which case word-teaching is not expected to be a useful intervention).

Accurate classification and diagnosis are crucial for improving communication between patients and their caregivers, and improving independence in individuals with PPA. Future research should aim to refine these diagnostic tools further and assess their impact on treatment outcomes, ultimately enhancing the quality of life for patients and their caregivers.

Notes

1. Although spared word comprehension is indicative of intact semantic lexicon, if word comprehension is impaired it could also be a sign of impairment in the phonological input lexicon (Bibb et al., 2000). To adjudicate between the two possibilities, written word comprehension should be used, which is expected to be spared when the deficit is in phonological input, but impaired when the deficit is in the semantic lexicon. Similarly, spared nonword repetition indicates intact phonological output buffer, but impaired repetition can be also caused by a phonological input buffer impairment (Shallice & Papagno, 2019), in which case difficulty in input-only tasks (e.g., nonword matching) will also be present. The current study focuses of lexical retrieval and does not consider selective impairments in input. Crucially, all of the impaired participants in the current study had errors in naming, and therefore none of them had selective input impairments.

2. Whereas some approaches (e.g., Levelt, 1989; Levelt et al., 1999) assume that the same component stores both lexical and lexical-syntactic information, such as grammatical gender, there is evidence that lexical-syntactic information is stored separately in a syntactic lexicon (Biran & Friedmann, 2012).
3. The same features can be symptoms of a combined impairment in the input and output phonological lexicons that does not involve any semantic or conceptual components. Such deficit is consistent with the core features of impaired naming (due to phonological output lexicon impairment) and impaired (auditory) single-word comprehension (due to the phonological input lexicon impairment), and with the supporting features of surface dyslexia (phonological output lexicon), and spared repetition (if tested using non-words).
4. In addition, when only one test was available, we never determined an impairment based on a single error, of any kind. This created the following threshold used for characteristic errors: Conceptual system > 1; Semantic lexicon > 3, phonological lexicon > 3; phonological output buffer > 1.
5. This created the following thresholds: picture association < 95%, word-picture matching < 91%
6. None of the participants who did not undergo the picture association tasks had more than one characteristic conceptual impairment error, and none of them presented with difficulty in object knowledge in conversation, and therefore none of them was classified as having a conceptual impairment.

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Data availability statement

The authors confirm that the data supporting the findings of this study are available within the article.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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