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Lexical retrieval beyond the single word: Modelling the production of alternating verbs

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ABSTRACT
Lexical retrieval is commonly studied in the context of single words, even though words are usually produced within sentences. We present a framework for investigating the interplay between lexical retrieval, argument structure, and morphology. We propose a model for the retrieval of alternating-verbs, which, in Hebrew, are morphologically marked based on argument structure. We tested 23 Hebrew-speakers with aphasia, first identifying their functional locus of impairment within a lexical retrieval model for single words, and then administering a test battery to assess their production of alternating verbs within sentences. We found that the conceptual system, the semantic lexicon, the syntactic lexicon, the phonological output lexicon, and the phonological output buffer, each plays a unique role in retrieving morphologically-complex verbs, yielding a different error pattern when impaired. These error patterns are predicted by the proposed model for retrieval of alternating verbs with their argument structure and morphology.

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1. Introduction

Lexical retrieval is a central theme in the neuropsychological study of language and language impairments. It is modeled as a cascade of cognitive components that begins with a single, abstract, non-linguistic concept, and ends with a single phonetic string that the speaker can articulate – a word. Accordingly, lexical retrieval abilities in the lab and in the clinic are usually assessed using tasks that examine the production of single words (typically, nouns) based on pictures or definitions. The type of errors patients make in the production of a single word points to the impaired stage in the process. Although models of lexical retrieval are useful for describing a broad range of lexical impairments, they are limited to an unnatural set of linguistic units: single words. However, words in the wild rarely appear in isolation. Words are usually used as parts of phrases and sentences. A word's sound and meaning may be affected by its role in these larger linguistic units, and therefore its retrieval cannot be fully described without reference to these units. Furthermore, words themselves are non-atomic: they are often constructed of smaller meaningful units, morphemes. Morphology acts as an interface between single words and higher level considerations, since words in some languages bear morphological markings based on their role in the sentence.

In this paper we offer a neuropsychological model for the production of morphologically complex verbs within sentences. The empirical domain on which we focus is alternating verbs (The window **closed**; Dan **closed** the window), which, in Hebrew, are morphologically marked based on their argument structure. The model demonstrates how words are retrieved within the context of sentence production. In this section we begin by presenting previous research on lexical retrieval, and, after describing the morphological properties of Hebrew, we also present previous research on Hebrew morphology and what it currently lacks. This sets the stage for the presentation of our model for the production of alternating verbs in Section 2.

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1.1. Current models of lexical retrieval

As a starting point, we assume a model of lexical retrieval developed by neuropsychologists of language and cognitive psycholinguists (Butterworth, 1989, 1992; Dell, 1986; Ellis & Young, 1996; Friedmann et al., 2021; Garrett, 1975; Levelt, 1989; Levelt et al., 1999; Morton, 1970; Nickels, 1997; Patterson & Shewell, 1987, among others). The model is presented in Figure 1, and in this section we describe and specify the roles of each of its components.

1.1.1. The conceptual system

In the first stage of lexical retrieval, a conceptual representation is formed. The nature of such representations is debated in philosophy and psychology (Fodor, 1998; Frege, 1918/1956; Rips & Medin, 2005; Rosch & Mervis, 1975; Wittgenstein, 1953). It may include relevant images, intentions, memories and associations, or other representations that are sufficient to activate an item in the semantic lexicon. The conceptual system is a pre-lexical component. However, it is an essential component in every model of lexical production, as Pfau (2009, p. 302) put it "a prerequisite for the generation of an utterance is a communicative intention of a speaker, the wish to convey some message". A deficit in the conceptual system is not a deficit in a language-specific component, but it has consequences for the ability to use and understand language. An impairment to this component is diagnosed based on difficulty understanding and producing ideas, objects, and pictures, even when the task does not require language (Friedmann et al., 2013; Nickels, 1997).

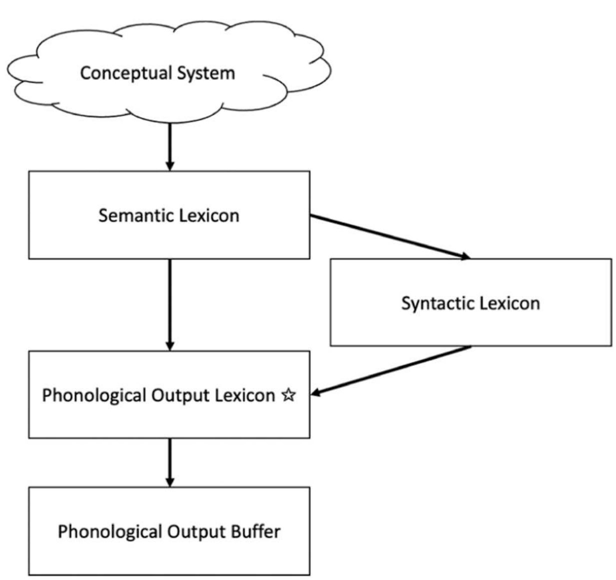

Figure 1. A neuropsychological model for lexical retrieval.

1.1.2. The semantic lexicon

The semantic lexicon stores entries that are minimally a set of semantically-organized pointers to the relevant entries in other lexicons: phonological representations in the (input and output) phonological lexicons, orthographic representations in the (input and output) orthographic lexicons (Butterworth, 1989), and syntactic features in the syntactic lexicon. The lexical items in the semantic lexicon are also linked to the general non-linguistic conceptual system, either by a one-to-one correspondence between a concept and a lexical item, or by a more complex system of semantic features (e.g., Katz & Fodor, 1963). The semantic lexicon is responsible both for input and output. An impairment in the semantic lexicon is diagnosed based on semantic errors in production and comprehension (e.g., "cat" → "dog") (Howard & Orchard-lisle, 1984; Nickels, 1995, 1997). Unlike a deficit in the conceptual system, when only the semantic lexicon is impaired, non-linguistic tasks are expected to be intact (Friedmann et al., 2013; Nickels, 1997).

1.1.3. The syntactic lexicon

The syntactic lexicon stores information relevant to the incorporation of words into the syntactic structure, such as grammatical category, grammatical gender of nouns, and argument structure for predicates (verbs as well as some nouns and other lexical categories, Luzzatti & Chierchia, 2002; Tabossi et al., 2002). Biran and Friedmann (2012) proposed that lexical-syntactic information is stored in a seperate component, the syntactic lexicon (see also Dickey & Warren, 2015) . An impairment to argument structure in the syntactic lexicon is diagnosed based on argument structure errors, e.g., argument additions, omissions, and substitutions within sentences (e.g., producing the sentence *John bought* without an object).

1.1.4. The phonological output lexicon

The phonological output lexicon stores the phonological representation of lexical items. We assume, following Friedmann and Coltheart (2017) and Friedmann et al. (2021), that entries in the phonological lexicon consist of stems and, for each stem, the affixes that are (idiosyncratically) compatible with it

(STARs, **St**em **A**ffix **R**egistries). For example, the stem "*govern*" is compatible with the suffix "*-ment*", whereas the stem "*dark*" is compatible with the suffix "*-ness*", so that in the phonological lexicon the stem "govern" appears with the STAR "*-ment*" (together with "*-or*" and other affixes). In Hebrew, stems are a set of consonants (and sometimes vowels) that may correspond to the classical notion of the Semitic root, and STARs are derivational morphological patterns.

An impairment in the phonological lexicon is diagnosed based on difficulty retrieving words ("don't know" responses and long hesitations), semantic errors (when a phonological representation cannot be activated, the patient articulates a related word and often rejects it, Caramazza & Hillis, 1990), and phonological errors (cat→cap) in some cases, and not a large portion of the errors (Gvion & Biran, 2023). Difficulty in retrieval due to an impairment in the phonological output lexicon is characterized by a word frequency effect (i.e., lower-frequency words are more difficult to retrieve) (Jescheniak & Levelt, 1994). Additionally, patients make regularization errors in reading irregular words aloud (a form of surface dyslexia, see Gvion & Friedmann, 2016). Finally, patients with this impairment do not have difficulties in word comprehension, nor in the reading and repetition of nonwords (unless there is another impaired component). Difficulty in the phonological lexicon can either be specific to accessing the stem, or a deficit to both the stem and its STARs (Friedmann et al., 2021).

1.1.5. The phonological output buffer

The phonological output buffer is a short-term memory component that assembles phonological strings from basic units and maintains the phonological information until it is fully articulated. An impairment in the phonological output buffer causes phonological errors such as phoneme or syllable omission and substitution, epenthesis and metathesis (Caramazza et al., 1986; Haluts et al., 2025; Shallice et al., 2000). Dotan and Friedmann (2015) showed that patients with a phonological output buffer deficit make whole-unit errors. Whereas for phonemes of the stem they produce omissions, substitutions, and additions of phonemes (*tree* → *tee, free*), in multi-digit number production they make number-word substitutions (e.g., *three* → *four*), and in morphologically complex words they make morphological errors:omissions and substitutions of whole derivational and inflectional morphemes (*hoping* → *hoped*). These findings about the selectivity of errors for different stimuli led Dotan and Friedmann (2015) to stipulate that there are several mini-stores accessible to the phonological output buffer that store phonological building-blocks of various sizes, so beyond a storage for phonemes, there are also mini-stores for morphemes, number words, and function words (Haluts et al., 2020). While assembling the output, the phonological output buffer uses different kinds of building blocks.

An impairment in the phonological output buffer is diagnosed based on poor repetition of words and non-words including a length effect (i.e., longer words induce more errors in reading and repetition), phonological errors in reading non-words, low phonological working-memory, and whole-unit errors in numerals, function words, and morphological affixes (Dotan & Friedmann, 2015; Friedmann et al., 2013; Shallice et al., 2000).

1.2. Verbal alternations

Two verbs are alternating if they have a systematic relation in their argument structure and meaning. For example, the two instances of the English verb "close" in (1a-b) demonstrate an alternation: in the two cases the core meaning is similar (it refers to the same event), and the two instances of the verb have a systematic relation in argument structure: in (1a) there is only one argument ("window"), which is, descriptively, the theme of the event, whereas in (1b) there are two arguments, a theme ("window") and a cause or an agent ("John").

(1) a. The window **closed**.
    b. John **closed** the window.

Since many languages distinguish morphologically between two alternating verbs (see Section 1.2.1), retrieving an alternating verb in these languages requires the speaker to retrieve the target argument structure and the matching morphological structure to integrate the verb in the correct syntactic structure. This potentially requires concerted action between all of the cognitive components described in Section 1.1, and specifically a connection between the syntactic lexicon that stores argument structure to the phonological lexicon that stores morphological structure that matches the argument structure. Because of the tight relation between argument structure and word structure, alternating verbs are a suitable testing ground for examining the relation between lexical retrieval and sentence level processes.

The current study focuses on two groups of alternations: causative[1] (e.g., "close") and reflexive (e.g., "shave") alternations. In English, the two instances of a verbal alternation are usually homophonous, e.g., there is no morphological difference between the transitive and intransitive form of "close" in (1). This is not the case for all verbs in English, as there are some verb pairs in English that are not homophonous, for example the causative of "rise" is "raise" (that roughly means "to make something rise").

1.2.1. Hebrew verbal morphology

Hebrew, a Semitic language, has non-concatenative morphology, namely, it is based on root-pattern structure rather than linear affixation. Most inflectional and derivational morphemes are not linearly stringed to the root, but discontinuously modify it . The Semitic root is understood in classical grammars (and adopted by McCarthy, 1981 and following work) as an ordered set of three (and sometimes more) consonants, which has a phonological realization only when modified by a pattern (termed *binyan* in the verbal domain and *mishkal* in nouns and adjectives), which may contain vowels and additional consonants. Verbs in Hebrew must have the root and pattern structure, as do most nouns and adjectives. In addition, verbs, nouns, and adjectives are marked for inflection (number and gender for nouns and adjectives; person, number, gender, and tense for verbs), which is also usually realized discontinuously.

In this paper, patterns are represented using a notation that includes the fixed consonants and vowels of the pattern, with the root consonants (C) embedded between them. The verbal domain consists of 5 patterns: CaCaC, CiCeC, niCCaC, hitCaCeC, and hiCCiC,[2] and all verbs are marked by a verbal pattern. To exemplify, the verb *hitmid* ("persevere") is composed of the consonantal root TMD and the hiCCiC pattern. In this case, the root TMD can only appear with the hiCCiC pattern in the verbal domain, and the speaker must memorize this pairing, i.e., encode the pattern that is relevant for the root TMD in long term memory. In the case of alternating verbs, selection of pattern has a grammatical contribution to the interpretation of the verb.

1.2.2. Alternating verbs in Hebrew

In many languages a morphological distinction between alternating verbs is the default. These languages have ways of marking one alternant or both, causing a morphological contrast between the alternants. Hebrew is such a language. The Hebrew sentences corresponding to (1) are in (2). Whereas in English both verbs are realized asthe same word, *closed*, in Hebrew they have a separate morphological form for each argument structure.

(2) a. ha- xalon **nisgar**[3]
The-window closed$_{\text{INTRANSITIVE}}$
b. Dan **sagar** et ha-xalon
Dan closed$_{\text{TRANSITIVE}}$ ACC the-window

Alternating verbs share a root, but usually each alternant has a different pattern, i.e., a different derivational morphology. In (2a), *nisgar* (close$_{\text{INTRANSITIVE}}$) and *sagar* (close$_{\text{TRANSITIVE}}$) share a root (SGR), but *nisgar* is in the niCCaC pattern, whereas *sagar* is in the CaCaC pattern. The combination of a root and a pattern is linked to the number of participants in the event.

This alternation in pattern is not regular, nor fully predictable: Whereas some verbs in niCCaC can alternate with CaCaC, other verbs in niCCaC alternate with hiCCiC (e.g., *nixšal-hixšil*, "fail") or CiCeC (*nirpa-ripe*, "cure"). Although the system is not fully predictable, there are restrictions on the possible pairs of patterns (Arad, 2005). Figure 2 is a sketch of the relation between argument structure and morphology in Hebrew.

1.2.3. Non-alternating and pseudo-alternating verbs

All verbs in Hebrew, not only alternating verbs, must appear in a morphological pattern. Whereas in alternating verbs, the morphological pattern marks the derivational relation between the alternants, in non-alternating verbs the pattern does not serve this function, and the marking is idiosyncratic[4]. Non-alternating verbs can appear in one of the five verbal pattern. For example, *hifgin* ("protest") is composed of the root PGN which can only appear with hiCCiC in the verbal domain. Some verbs share a

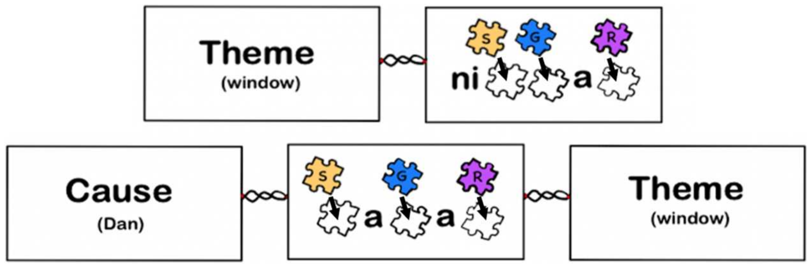

Figure 2. Consonantal roots are inserted into verbal patterns (which consist of vowels and sometimes additional consonants). The combination of root and pattern is linked to argument structure in alternating verbs. Examples given for the verbs *nisgar* (“*close*$_{\text{INTRANSITIVE}}$”) and *sagar* (“close$_{\text{TRANSITIVE}}$”).

root but are not strongly related to each other in meaning, in grammatical properties, or in a derivational paradigm. For example, *xalam* (“dream”) and *hexlim* (“recover from illness”) share root consonants, and, like all Hebrew verbs, are marked with a morphological pattern (CaCaC and hiCCiC respectively), but there does not seem to be an inherent reason that “dream” is in CaCaC and “recover” is in hiCCiC and not the other way around. The pattern does not seem to contribute to the meaning, nor do the two verbs seem to be derivationally related. We call such pairs pseudo-alternating verbs, since they appear in patterns that may participate in verbal alternation with other roots (e.g., the alternating pattern pair CaCaC-hiCCiC used in the pseudo-alternating pair *xalam-hexlim* is the same pair of patterns used in the alternating pair *caxak* – *hicxik*, “laugh” – “make someone laugh”). Pseudo-alternating verbs sometimes have a shared meaning component[5], but they are not alternating in the same sense as alternating verbs since the relation between the meaning and argument structure within a pair is not systematic.

1.2.4. Previous research on root and pattern morphology

The notion of root from classical grammar is still central in theoretical linguistics (Harley, 2014; McCarthy & Prince, 1990, among others). Some of this work revolves around a debate on the representation of roots and patterns in the morpho-phonological component (Bat-El, 1994; Faust, 2019; Hever & Faust, 2010, among others), and on the way in which verbal patterns reflect abstract syntactic structure (Arad, 2005; Doron, 2003; Kastner, 2020).

In psycholinguistics, research has clearly demonstrated that verbs are indeed decomposed into a root and a verbal pattern during visual processing, using several methodologies (Deutsch et al., 1998; Deutsch & Frost, 2003; Deutsch & Meir, 2011; Feldman et al., 1995; Frost et al., 1997). However, no study has specifically examined the psycholinguistics of alternating verbs in Semitic languages, and there is currently no neuropsychological model describing the lexical retrieval of alternating verbs.

1.3. The contribution of the new model: What we seek to explain

The current study uses empirical evidence from aphasia to provide a theoretical account for the production of alternating verbs within sentences. Whereas the psychological reality of morphological structure has been demonstrated, and the cognitive model for whole-word retrieval is well-established, there is currently no model for the way morphologically complex verbs, including alternating verbs, are retrieved when their morphological structure is related to their argument structure.

This makes the new model and the current study the first exploration of word production to study the interplay between argument structure and Semitic morphology, and our new cognitive neuropsychological model the first model to describe the stages of production of morphologically complex verbs from conceptualization to morphological and phonological realization. The model aims to account for the way morphological patterns are selected in accordance to argument structure, and the way argument structure is selected in accordance to the speaker’s intended meaning.

It is also the first study to examine these questions using language impairments. Describing the pattern of deficit in alternating verb production that results from an impairment in each stage of the model contributes to cognitive neuropsychological theory by shedding light on the specific role of each stage.

Understanding each impairment's implication on processing morphologically-complex words also bears clinical fruits, as the precise description of the functioning of each stage and the effect of an impairment in each stage is crucial in setting the ground for targeted treatment for the production of morphologically complex verbs, especially in a language in which every verb is morphologically complex.

2. The proposed model

Models of lexical retrieval have seen considerable development over the years, with work that accounts for various psychological and neuropsychological effects in numerous languages.

Although much work has been dedicated to modelling lexical retrieval in different languages, no model of this sort, to our knowledge, directly tackles the phenomenon of verbal alternations in Hebrew or any other language. Essential changes in the architecture of models of lexical retrieval would be required in order for them to successfully account for alternating verbs and alternant substitution in aphasia: Alternating verbs are single words, but the selection of one alternant over the other in sentence production requires the consideration of their syntactic and thematic environment. The choice between two morphological patterns for a specific root is made according to the number of arguments in the sentence: typically, one of the alternants has one additional argument compared to the other. For example, in the case of the two alternants of "close", one alternant has a single argument (a theme), the other has two arguments (a cause and a theme).

Since models of lexical retrieval were not originally designed to account for verbal alternations in Hebrew, they lack certain properties that are essential for this task. The first type of models (e.g., Aitchison 2012; Butterworth, 1989; Dell, 1986) does not refer to derivational relations between words at the level of the semantic lexicon, or assume that in most cases derivational affixes are stored pre-assembled with the stem, even if they are later decomposed. Therefore, they would incorrectly have to assert that two alternants are completely separate entities at all stages of the derivation. Alternant substitutions, in this type of models, would have to be explained as an instance of semantic substitutions, and therefore the prediction would be that there will not be a selective impairment causing alternant substitutions (e.g., raise → rise), without other semantic errors (raise → lift; cat → dog). Similarly, presence of semantic errors would predict alternant substitutions. We will show that alternant substitutions are independent from a deficit at the semantic level and may occur independently of other semantic and morphological errors.

The second type of models (e.g., Levelt et al., 1999; Roelofs & Ferreira, 2019) has some mechanisms for representing morphologically complex words, but none of them can account for verbal alternation. For example, in Levelt et al. (1999), lemmas have diacritic parameters whose values later determine the realization of inflection such as tense and agreement for verbs, some of which are based on conceptual information and some determined during grammatical encoding (Bock & Levelt, 1994). However, alternating verbs are not an instance of inflectional morphology, since they are not entirely predictable, and speakers must largely rely on memorizing root and pattern pairings (Arad, 2005; Katz & Friedmann, in press). Treating verbal patterns as inflection would also generate an incorrect prediction, since errors in verbal patterns do not always cooccur with errors in inflectional categories as shown by the current work. Another mechanism for complex morphological words is to derive them by multiple concepts. Levelt et al. (1999) also proposes that low-frequency words with productive derivational morphology, like words in the *X-ful* template (*bucketful*) are derived by the activation of two lemmas, one for the stem, and one for the suffix (*-ful*). Pattern morphology is unlikely to be derived in this manner, since patterns are not productive as affixes in the same sense as *-ful*, and they also do not have constant conceptual content separable from the stem. Finally, Levelt et al. (1999) propose that

> Words with bound derivational morphemes form a special case. These morphemes typically change the word's syntactic category. However, syntactic category is a lemma level property. The simplest story, therefore, is to consider them to be single-lemma cases, carrying the appropriate syntactic category. (p.12)

Verbal patterns are bound derivational morphology, and theydetermine the verb's sub-category, i.e., its argument structure. However, treating them as separate lemmas would encounter the same problem the first type of models encounters, namely, an incorrect prediction about the lack of a selective impairment in alternating verbs. Apart from the fact that existing models cannot readily account for Hebrew verbal morphology, they also lack mechanisms for explaining the co-occurrence of certain morphological forms with certain argument structure configurations, which is crucial for explaining how the correct alternant is selected in a sentence.

The crux of our proposal is that a single item in the semantic lexicon representing an event may correspond to several different options for argument structure in the syntactic lexicon. For example, a closing event may correspond either to a verb with one argument or to a verb with two arguments. The argument structure in the syntactic lexicon is selected based on the conceptual message representation (e.g., when the speaker wants to talk about two participants in the action, they select a transitive argument structure in the syntactic lexicon). The two alternative argument structure representations in the syntactic lexicon correspond to the same root in the phonological lexicon, but to different morphological patterns, represented by STARs. The phonological output buffer assembles the root with the (pre-assembled) morphological pattern. Syntax manipulates (i.e., merges and moves) the abstract lexical entries and constructs a hierarchical structure before the lexical entries receive phonological content in the phonological lexicon. The proposed model is presented in Figure 3.

2.1. The components in the proposed model: Retrieval of alternating verbs within sentences

2.1.1. The conceptual system – The event, participants, and their roles are represented

The speaker has a representation of what they want to say and emphasize in the utterance. We assume that this representation minimally consists of the event, the participants in the event, their conceptual role in the event, as well as some aspects of pragmatics of the message the speaker wants to generate (i.e., which role they would like to emphasize, which information they would like to hide from the interlocutor, etc.). The representation that we assume in the conceptual system is sufficient to determine at a later, grammatical, stage the argument structure of the verb and, in Hebrew, its form.[6] After the initial idea has been constructed at this level, the process is automatic and deterministic. Since we assume that the conceptual system is responsible for representing the participants in the event and their conceptual role, patients with impairment in the conceptual system involving difficulty in conceptual roles are predicted to make alternant substitutions (among other errors involving conceptual roles of arguments in alternating and non-alternating verbs). If subsequent grammatical components are intact (e.g., the syntactic lexicon), substitutions are predicted to result in grammatical sentences (e.g., "John dropped the vase" → "John fell", but not "John fell the vase").

2.1.2. The semantic lexicon – An entry without argument structure is activated

In terms of sentence construction, the semantic lexicon, where a non-linguistic concept receives a linguistic representation for the first time, is where numeration (Chomsky, 1995) begins, i.e., the stage in which abstract lexical items are selected. We suggest that at this stage, two alternants of the same event are represented by a single entry, since they both denote the same event. For example, *break*$_{\text{TRANSITIVE}}$ and *break*$_{\text{INTRANSITIVE}}$ both represent the event of breaking, the difference is in their argument structure (which is not represented at this stage of the derivation) and in the participants of the event on which the speaker wants to turn the spotlight (e.g., whether or not the speaker wants to mention the cause of the event). Our model does not predict that the semantic lexicon will have a special role in the production of morphologically complex verbs in comparison to other verbs. Therefore, in the case of a selective impairment to the semantic lexicon that does not involve other components we do not expect morphological errors.

2.1.3. The syntactic lexicon – Argument structure is selected based on listed options and event representation

Two alternants that share a single representation in the semantic lexicon (the abstract lexical item of the verb), have different argument structures. We propose that representations in the syntactic lexicon are complex representations composed of predicates, and their MOONs (**M**orphological **O**ptions **O**f **N**umeration), which list the argument structures that are compatible with the event in a given language. The correct MOON is selected based on the selection

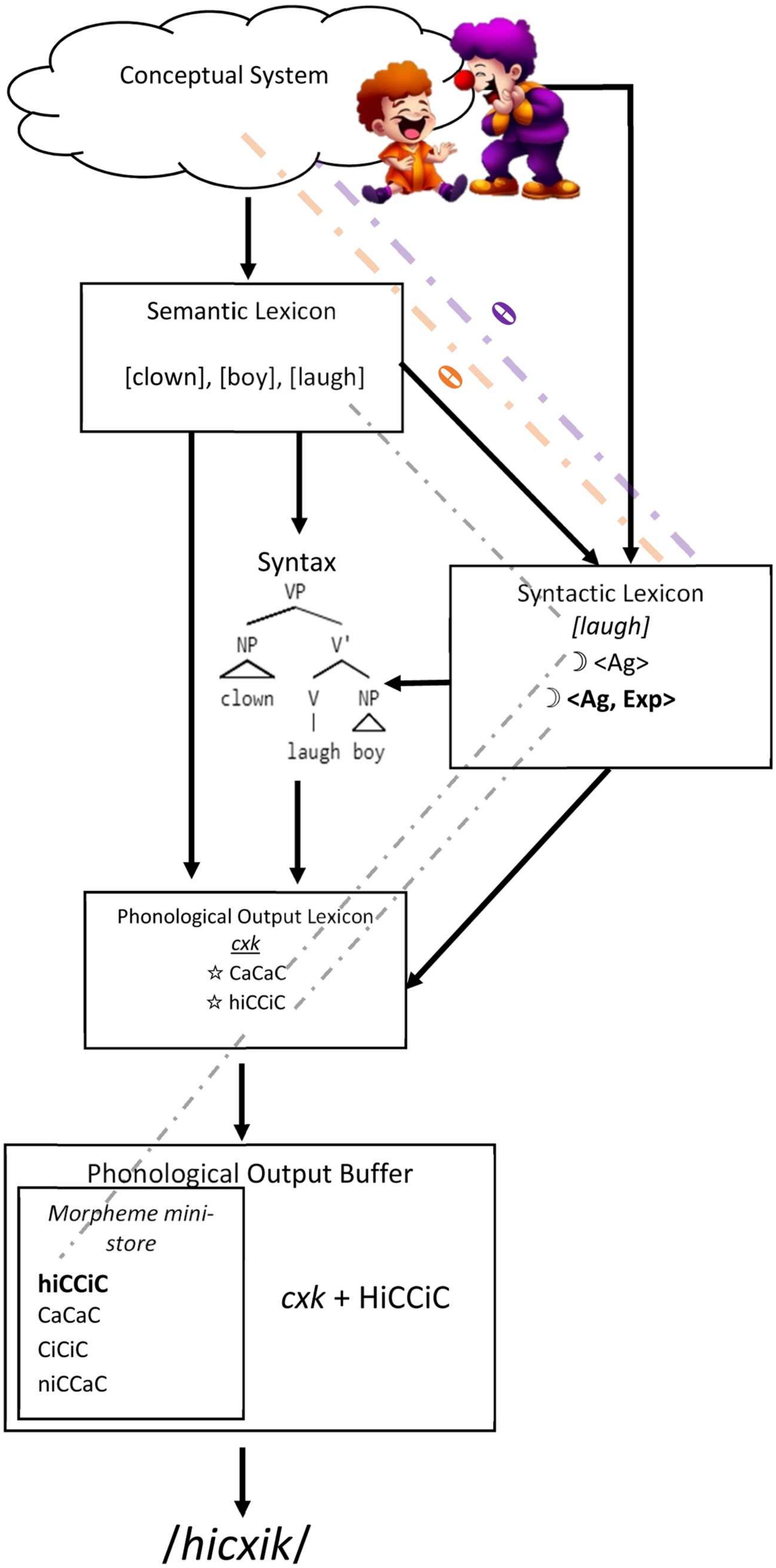

Figure 3. The proposed model for the production of alternating verbs, with an example of a derivation of the alternating verb *hicxik* ("laugh$_{\text{TRANSITIVE}}$", "make someone laugh").

made in the conceptual system about the number and the role of the participants in the event. Each MOON is directly connected to a STAR (Stem Affix Registry) in the phonological output lexicon (see Section 2.1.5.). Since the syntactic lexicon is responsible for the selection of the relevant argument-structure alternant, which is represented in the model as selection of MOON (which in turn selects a STAR), we predict that in addition to predicate argument structure errors, patients with a deficit in the syntactic lexicon will also make alternant substitution errors, resulting argument structure violations (e.g., "John dropped the vase" → *"John fell the vase"). Since the impairment is specific to argument structure, these patients are not expected to make morphological substitutions in non-alternating verbs, in nouns, or in inflectional morphology.

2.1.4. Syntax – Sentence structure is constructed

The syntactic component receives input from the semantic lexicon (abstract lexical items from the numeration) and from the syntactic lexicon (argument structure and grammatical gender). The output of the syntactic component is a hierarchical structure of abstract items (Chomsky, 1965, 1993, 1995, among others). A set of grammatical rules at the interface between syntax and the syntactic lexicon is responsible for mapping the arguments in the sentence to their correct syntactic position based on the argument structure selected in the syntactic lexicon. The fruits of the syntactic tree are picked by the phonological output lexicon and the phonological output buffer. The placement of the syntactic component between the semantic lexicon and the phonological output lexicon, namely, the proposal that the phonological form of words is accessed after the syntactic structure has been constructed, is a neuropsychological expression of the linguistic notion of late-insertion, made popular by distributed morphology (Halle & Marantz, 1993). (For a discussion of the relation between the current model and distributed morphology, see Appendix F.) It is also similar to "grammatical encoding" in Levelt's (1989) model, in which the "formulator" constructs a hierarchical "surface structure" from lemmas (which are comparable to items in the semantic and syntactic lexicon in our terminology), which precedes "Phonological encoding", and a phonetic plan is built based on lexical forms (which are comparable to items in the phonological lexicon in our terminology). The operations available for syntax are beyond the scope of this paper, and the model can work under various theories of syntax.

2.1.5. The phonological output lexicon – Morphological pattern is selected based on the argument structure of a given verb

We assume following Friedmann et al. (2021) that representations in the phonological output lexicon are complex representations composed of stems, which in Hebrew are usually roots , and STARs (Stem Affix Registries), the list of affixes that are compatible with each root. The STARs contain only idiosyncratic morphological information about the entries. For verbs, the STARS include information about the verbal pattern in which the root can appear (no information about regular inflection is stored in the STARs, because these apply to all verbs and are not idiosyncratic). For alternations, the stem is the shared root, and the STARs are the specifications of the alternating patterns. A crucial point in our model is that MOONs are directly linked to their STARs, so an intransitive MOON in the syntactic lexicon is linked to the STAR in the phonological lexicon which represents the verbal pattern for the intransitive alternant for a specific root, and a transitive MOON links to the STAR with the pattern of the transitive alternant. Since verbal (and nominal) patterns are determined by the STARs, patients with a deficit in access to STARs in the phonological lexicon are expected to substitute patterns in alternating verbs. Importantly, however, they are expected to make such errors not only in alternating verbs, but also in non-alternating verbs, and in nouns.[7] Patients with a deficit in the phonological output lexicon that involves only roots (and not STARs) will not make morphological errors.

2.1.6. The phonological output buffer – The root is assembled with the pattern

The phonological output buffer receives an abstract phonological representation of the stem (root) from the phonological output lexicon, and provides its phonetic content. The phonological form of the affixes, including the patterns, are held in the long-term morphological mini-store at the level of the phonological output buffer (or a separate unit accessible to the buffer), and are activated by the STARs in the phonological lexicon.

The phonological output buffer assembles the root with the phonological form of the pattern, retrieved from the mini-store, together with inflectional morphology (possibly, idiosyncratic-lexical derivational morphology is attached before inflectional morphology). Since the phonological output buffer assembles the root with a pattern for all morphologically complex words, and is also responsible for inflectional morphology, patients with a deficit in the phonological output buffer are expected to substitute patterns in alternating verbs, non-alternating verbs, and nouns, and will also substitute inflectional morphology, such as tense and agreement.

At this point following the conception of the event in the conceptual system, the selection in the semantic and syntactic lexicons, the activation of the root and pattern in the phonological output lexicon and the assembly in the phonological output buffer, the alternating verb is ready to be articulated. An example for the stages of production of an alternating verb is provided in Appendix A.

3. Methods

To put the proposed model to empirical test, we tested Hebrew-speaking patients with impairments in various stages of the process. We first identified the functional locus of impairment within the lexical retrieval process of each patient using a wide battery of tests that do not involve verbal alternations. Patients' performance in each of these tasks was compared to non-impaired controls using the *t*-test for case–control comparison (Crawford & Howell, 1998; Crawford & Garthwaite, 2002) to determine which language functions were impaired. Performance significantly below controls was considered impaired. At the next stage, to examine the role of each functional component in the production of alternating verbs, we administered a novel test battery (HIFIL, Katz & Friedmann, 2020) that we designed to assess in detail the production of alternating verbs and their morphology, in comparison to various types of non-alternating verbs and other kinds of morphology. Performance in the HIFIL battery was also compared to non-impaired controls using the same method. The rationale was the following: if we identify a patient with a selective deficit in a certain component of the lexical process, we can then examine what they can and cannot do, and see if their performance pattern is in line with the component's role in the alternating verbs model.

3.1. Participants

Twenty-three patients participated in the study: 17 Hebrew-speakers with aphasia that have an impairment in the lexical retrieval process (Table 1), and six participants with early-acquired language impairment due to thiamine deficiency (see Fattal et al., 2011; Katz et al., 2022 for the long-term effects of thiamine deficiency on language). These six participants are only presented in Appendix E.

3.1.1. Participants with Aphasia

All the participants had approached the Tel Aviv University Language and Brain Lab for comprehensive language assessment, and recommendations for targeted treatment.

In the general language assessment stage, upon identifying difficulty in lexical retrieval through impaired performance in picture naming or errors in spontaneous speech, or a deficit in the syntactic lexicon manifested as verb complement errors in sentence production, participants were tested using a wide battery of additional tasks to determine their functional locus of impairment (see Section 3.1.3 and Table 2). Participants who showed an impairment that could be unequivocally ascribed to a specific component in the lexical retrieval process and who agreed to be tested further were requested to participate in additional testing of morphology and alternating verbs, and the ones who agreed were included in the study as case studies. These patients have a deficit in the conceptual system, the semantic lexicon, the syntactic lexicon, the phonological output lexicon, or the phonological output buffer.

We present in detail six case studies of patients with aphasia with a selective deficit in each component of the model, including a full diagnosis of functional locus of impairment and the selective impairment in morphology using several tasks.

Table 1. Demographic information.

Initials	Age	Sex	Education	Etiology	Time post onset	Damaged regions	Patient group
AL	69	M	12	CVA	11 months	Left temporo-occipital region	Detailed case studies
HY	50	F	>12	CVA	21 years	Left fronto-temporal areas	
CN	61	F	>12	PPA	5 years	Left temporal pole	
HH	73	M	>12	CVA	1 year	Left basal ganglia	
RR	37	M	>12	CVA	days	Left MCA (M1) and lentiform nucleus	
SH	23	F	12	CVA	days	left fronto-parietal regions	Patients from Biran and Friedmann (2012) (PASTA battery)
SN	62	M	8	CVA	2.5 months	Left temporo-parietal areas	
RT	58	F	8	CVA	7 years	Left ischemic infarct	
AO	73	M	>12	CVA	1 month	Left MCA involving temporo-parietal areas	
VV	64	M	>12	CVA	days	Left parieto-occipital	Patients with a phonological output buffer impairment (sentence completion task)
AV	61	F	12	CVA	15 months	Right MCA	
SK	87	M	12	CVA	1.5 years	Left temporo-occipito-parietal	
EL	53	M	>12	Glioma	1.5 years	Left temporo-parietal	
DL	58	M	>12	CVA	2 years	Left MCA	
UB	75	M	>12	PD	4 years	N/A	
BG	71	M	>12	PD	6 years	N/A	
AG	53	M	>12	PD	5 years	N/A	

Abbreviations: M – Male, F – Female, CVA - cerebral vascular accident, PD – Parkinson's disease, MCA - middle cerebral arter, N/A - not available.

In addition to the six case studies, we introduce 11 patients who were tested with a more limited morphological battery, who have a deficit either in the syntactic lexicon (3 patients) or in the phonological output buffer (8 patients). Three patients with a deficit in the syntactic lexicon were tested using the PASTA test battery (see Table 2 for information about what the battery examines). These participants were reported in Biran and Friedmann (2012), and we reanalyze their results considering the research questions of the current paper. Eight patients, who have a deficit in the phonological output buffer, were tested with the sentence completion task from the HIFIL battery. Five of these participants had post-stroke aphasia, and 3 had progressive aphasia due to Parkinson's disease.

Table 2. The tasks and error types used to diagnose functional locus of impairment.

Cognitive component	Symptoms of impairment	Tasks in which the patient should fail
Conceptual system	Unrelated and semantic errors, impaired object knowledge. Deficits in both production and comprehension.	Picture association: Ma Kashur (Gvion & Friedmann, 2013). Picture naming: SHEMESH (Biran & Friedmann, 2004) Naming to definitions: (Gvion & Friedmann, 2013)
Semantic lexicon	Semantic errors in naming and in comprehension, intact reading aloud, intact object knowledge.	Picture naming: SHEMESH (Biran & Friedmann, 2004); word-picture matching (Friedmann, 2015)
Syntactic lexicon	Argument structure errors such as adding or omitting arguments (in non-alternating verbs), substituting prepositions with other prepositions or with direct objects.	Sentence production, sentence completion, grammaticality judgement of verbs with various argument structures PASTA battery (Biran & Friedmann, 2009)
Syntax	Difficulty with production, comprehension, and repetition of complex sentences with movement or embedding. Errors such as role substitutions in complex sentences, ungrammatical production, and impaired repetition of complex sentences.	Production of sentences with wh-movement: BAMBI Adif (Friedmann & Novogrodsky, 2002; Friedmann & Szterman, 2006; Novogrodsky & Friedmann, 2006), Zibuv (BAFLA battery, Friedmann, 1998) Comprehension of sentences with wh-movement: Zika Meguvana (Friedmann, 2010), ZST-TLAT (Friedmann & Novogrodsky, 2011) Repetition of sentences with and without wh-movement and embedding: PETEL (Friedmann, 2000)
Phonological output lexicon	Difficulty retrieving words ("don't know" responses), long hesitations (defined as >5 seconds), semantic errors, and (rarely) phonological errors. Word comprehension and reading and repetition of non-words is intact. Word frequency effect in naming. surface dyslexia in reading aloud. If there is no surface dyslexia, we conclude that the deficit is not in the lexicon itself but in access to the lexicon from the semantic lexicon (and not from the orthographic lexicon). If there are morphological substitutions in noun derivational morphology, we conclude that the deficit is also in access to the STARs.	Picture naming: SHEMESH (Biran & Friedmann) Reading: TILTAN (Friedmann & Gvion, 2003), which includes irregular words Production of morphologically complex words (picture naming, sentence completion) (Amorphia battery: Stark et al., 2018)
Phonological output buffer	Phonological errors, whole-unit substitutions of number words, function words, and morphemes. Difficulty in non-word repetition and non-word reading, limited STM spans	Word and non-word spans: FriGvi battery (Friedmann & Gvion, 2002) Non-word repetition: BLIP (Friedmann, 2003) Non-word reading: TILTAN (Friedmann & Gvion, 2003)

3.1.2. Control groups

For determining the functional locus of impairment of each participant we used existing normative data from the Language and Brain Lab database (the tests are referenced in Table 2). For the HIFIL test battery we recruited 89 participants overall for all tasks in two age groups: 20–42, and 50–66, to match participants' wide spectrum of ages. Recruitment was through social media, and participants were paid 15 NIS for a 10–20 minute testing period in which some of the HIFIL battery tests were administered, in person or via Zoom. All participants in the control groups had at least 12 years of education, and each control group included both men and women. More details on age of control groups for each test and comparison between patients' and controls' age is found in Appendix B. The study was approved by the Tel Aviv University Ethics Committee, and participants signed an informed consent form.

3.1.3. Diagnosis of the functional locus of impairment

We diagnosed each patient's functional locus (or loci) of impairment using tasks not directly related to alternating verbs. The tasks and error types we used to diagnose the functional locus of impairment for each case study are presented in Table 2. Error coding for background tasks was performed based on the specific task's design and instructions (see references within Table 2 for more information). The assessment process and the procedure we used to infer the functional locus of impairment for each participant are described in detail in Appendix D.

3.2. Materials: The HIFIL test battery – Production of alternating verbs

Once the locus of impairment of each patient was established, we moved to examine their production of alternating verbs. The HIFIL test battery, which we designed for this study (Katz and Friedmann, 2020), consists of five tasks testing transitive and intransitive alternants in causative and reflexive alternations in all patterns, in comparison with pseudo-alternating verbs and non-alternating verbs. Appendix C contains summaries of the types of stimuli used in each task in the HIFIL battery. Because of the unpredictable nature of work with patients, not all participants were able to participate in every task, or to complete all items in each task. When a patient performed only part of a task, comparison to a control group was conducted based on the completed part of the task. In such cases, we included the number of correct responses out of the total attempted items alongside the percentage of correct responses in the results section. In this section we describe the 6 tasks in the HIFIL test battery with some examples. There was no time limit for responses in any of the tests; the participants were given as much time to respond as they needed, and we only proceeded when the participant gave some response or asked to move on. Responses in the HIFIL test battery were coded as either correct or incorrect, and erroneous responses were coded for error type by the two authors: alternant substitution (with correct or incorrect argument structure), pattern substitution, tense error, agreement error, argument structure error (addition/omission/substitution of arguments), hesitation, definition, no response, "don't know", phonological error, or semantic error.

Throughout the paper we refer to "morphological errors" as a cover term for any error that involves addition/omission/substitution of a derivational or inflectional morpheme. We will show that morphological errors critically differ from one another, and that this can be predicted based on the underlying impairment. Therefore, where relevant, we specify the exact type of morphological error.

3.2.1. Sentence completion

The experimenter reads 48 sentences that include a missing verb, also presented visually. The first part of the sentence contains one alternant, printed in bold text and read by the experimenter with prosodic stress. The participant is asked to complete the sentence by saying an appropriate word related to the stressed word. The target is the other alternant, with an additional difference in inflection (to test inflection and to distinguish between real morphological errors and repetition of the given verb). An example for is provided in (3):

(3) *ha-menora* *b-a-salon* ***nidleka***
The-lamp.$_{\text{FEM}}$ in-the-living-room **turned**-on$_{\text{INTRANSITIVE.FEMININE}}$
ki Uri laxac al ha- meteg ve-____ ota.
because Uri$_{\text{MASC}}$ pressed on the switch and-____ her.
(Target: hidlik - turned-on$_{\text{TRANSITIVE.MASC}}$)
"The light in the living room turned on, because Uri pressed the switch and turned it on."

3.2.2. Rephrasing

The experimenter reads 49 very short stimulus sentences in which a single verb is missing. The stimulus contains a definition for the missing, target verb in a periphrastic construction: for causatives – an infinitival intransitive preceded by the verb *cause* (e.g., *cause to dance*), and for reflexives – a transitive verb with a reflexive pronoun (e.g., *shave himself*). The target is the alternant of the verb that is used in the periphrastic form, as exemplified in examples (4-5). The items in the task are the pattern combinations possible in Hebrew for causative and reflexive alternations.

(4) Causative:
Hu garam l-a-agartal lehišaver, hu ___ et ha-agartal. (target: *šavar)*
He caused to-the vase to-break$_{\text{INTRANSITIVE}}$, he ___ ACC the-vase. (target: broke$_{\text{TRANSITIVE}}$)
"He caused the vase to break, he ___ the vase".

(5) Reflexive:
Hu hilbiš et acmo, hu __ (target: *hitlabeš)*
He dressed$_{\text{TRANSITIVE}}$ ACC himself, he __ (target: *dressed*$_{\text{REFLEXIVE}}$)
"He dressed himself, he ___".

3.2.3. Sentence production to a given verb

The experimenter says a verb, and the participant is requested to produce a sentence with this verb. The test included 56 target verbs, 32 alternating (causative and reflexives) and 24 non-alternating (pseudo-alternating pairs and non-alternating verbs in hiCCiC).

3.2.4. Multiple choice sentence completion

A sentence completion task, with forced choice between four verbs. While the participant is looking at a page on which the sentence (with a missing verb) and the options are written, the experimenter says the sentence with the missing verb. The experimenter then says each of the four options for completion, while pointing at that option. The participant is asked to select the most appropriate option for completion by circling or saying it. One of the options is the correct alternant, another is the incorrect alternant and the other two are verbs in real patterns that do not exist for that root. All of the options have correct agreement morphology, and only differ in pattern. For example:

(6) *Ha-maim ___ et ha-yeladim še-sixku b-a-xuc*
The-water ___ ACC the-kids that-played in-the-outside
"The water ___ the kids that played outside."

hirtivu	*nirtevu*	*ritvu*	*ratvu*
wet$_{\text{TRANSITIVE}}$	wet$_{\text{INTRANSTIVE}}$	Non-existing word with the root RTV in CiCeC	Non-existing word with the root RTV in CaCaC

The test included 56 items, among them 8 items with "double agent" verbs, which are ambiguous between an alternating verb and a non-alternating verb. These verbs were presented twice, once in each context.[8]

3.2.5. Picture description

The participant is presented with 16 pictures and a question about the action of one of the participants in both written and oral form ("what is X doing?", "what is X doing to Y?"). The answer to the question is the verb (or a verb phrase) depicted in the picture. The target verbs are alternating transitives, reflexives, and pseudo-alternating verbs. An example is given in Figure 4 and example (7):

(7) Ma ha-arye ha-ze ose? (Target: mitraxec)
What the-lion the-this do? (Target: 'wash$_{\text{REFLEXIVE}}$')
"What does this lion do?"

Figure 4. An example of an item in the picture description task.

4. Results: Case studies of impairments in each component of the model

In this section we present the performance of patients with impairments in various components of the model. We present at least one patient with an impairment in each of the following components: the conceptual system, the semantic lexicon, the syntactic lexicon, the phonological lexicon with impaired access to roots/stems with preserved access to STARs, the phonological lexicon with impairments in access to roots/stems and to STARs, and the phonological output buffer. Patients' performance was compared to performance of the control group using *t*-test for case–control comparison (Crawford & Howell, 1998; Crawford & Garthwaite, 2002).

4.1. The conceptual system

AL is a 69 year-old man who was treated in a rehabilitation hospital following a stroke that involved his left temporo-occipital region. We concluded AL has a deficit in the conceptual system because of his unrelated errors in naming, and his difficulty in picture association. Table 3 summarizes the findings that led to his diagnosis.

AL had a distinct error pattern in the HIFIL test battery, which we attribute to his deficit in the conceptual system. In the rephrasing task, he made alternant substitution errors (examples (8–11)). Crucially, in all but a single case in which he used the incorrect alternant, he used the correct argument structure of the alternant he produced. I.e., his response was grammatical, but he substituted the roles in the sentence.

(8) **lead-in**: *hu garam le-mira lehišava, hu __ et mira (target: hišbi'a)*
He made to-Mira to-vow$_{\text{INTR}}$, he __ ACC Mira (vowed$_{\text{TRANSITIVE}}$)
Response: nišba le-mira
vowed$_{\text{INTR}}$ to-mira

(9) **lead-in**: *hu garam le-dana lehitkarev, hu __ et dana (target: kerev)*
He made to-Dana come-near$_{\text{INTR}}$, he __ ACC Dana (came-near$_{\text{TRANSITIVE}}$)
Response: hitkarev le-dana
Come-near$_{\text{Intr}}$ to-Dana

(10) **lead-in**: *hu garam le-šula lirkod, hu __ et Šula (target: hirkid)*
He made to-Šula dance$_{\text{INTR}}$, he __ ACC Šula (made-dance)
Response: rakad im šula
dance$_{\text{INTR}}$ with šula

(11) **lead-in**: *hu garam le-yossi lix'os, hu __ et yossi (target: hix'is)*
He made to-Yossi be-angry$_{\text{INTR}}$, he __ ACC Yossi (anger)
Response: ka'as al yossi
was-angry$_{\text{INTR}}$ on Yossi

For example, in sentence (11), AL used the intransitive alternant (*ka'as)* instead of the transitive alternant (*hix'is)* and reversed the thematic roles (instead of Yossi being angry, someone is angry at Yossi). However, AL did use the correct preposition for the intransitive alternant he used, which is only possible with the intransitive alternant (*al* – "on").

These errors are predicted by the model: AL has an impairment in the conceptual system, which, we suggest, is not only responsible for representing abstract concepts, but also for building a hierarchical conceptual representation of the relations between different concepts[9] and in the case of alternating verbs – representing the participants in the events and their roles in it.

The identity of the event was provided to him by the experimenter, and therefore he managed to access the correct abstract entry for the event. Still, since his conceptual representations of events are impaired, he has difficulty representing how many participants there are in the event, and what the role of each of them is. The conceptual system feeds the syntactic lexicon, and therefore if conceptualization of the event is impaired, input to the syntactic lexicon may be incongruent with the target event structure, and the incorrect argument structure (MOON) will be selected. However, since AL *does not* have an impairment in the syntactic lexicon or in grammatical knowledge governing thematic role assignment, once he selects a MOON, he has full knowledge of the selectional properties of the alternant. His spared syntactic lexicon (usually) prevents him from making argument structure errors such as using incorrect prepositions or selecting a wrong number of arguments for the verb he produces, and therefore his sentences are grammatical (as opposed to alternant substitution errors of patients with a deficit in the syntactic lexicon, as shown below). AL's performance in the battery is summarized in Table 4.

AL's performance in other tasks further reflects his conceptual impairment alongside his spared syntactic lexicon. Such cases were detected in the **sentence production to a given verb** task, where he used a syntactically correct phrasal category, but which was semantically and thematically inappropriate (examples 12–13).

(12) *hilbiš: hilbiš beged*
dressed$_{\text{TRANSITIVE}}$: dressed$_{\text{TRANSITIVE}}$ clothing

(13) *hic'idu: hem hic'idu et ha-derex l-a-beit sefer*
Marched$_{\text{TRANSITIVE}}$: they marched$_{\text{TRANSITIVE}}$ ACC the-way to-the-school

Table 3. AL's performance in tasks that led to the diagnosis of an impairment in the conceptual system.

Task	% Correct and error types	Comparison to controls
Picture naming	0%*** Unrelated and semantic errors, definition	*M* = 93%, SD = 7.5%, *N* = 30, *t*(29) = 12.20, *p* < .001
Naming to definitions	25% Unrelated and semantic errors	
Picture-picture association	83%***	*M* = 98%, SD = 3%, *N* = 30, *t*(29) = 4.92, *p* < .001

*** *p* < .001.

Table 4. AL's performance in the HIFIL test battery compared to controls.

Task	% Correct and error type	Comparison to controls
Sentence completion	100%^{ns}	$M = 99.2\%$, SD = 1.7%, $N = 10$, $t(9) = 0.45$, $p = .332$
Rephrasing	88%***, grammatically correct alternant substitutions	$M = 99.6\%$, SD = 1.2%, $N = 10$, $t(18) = 67.9$, $p < .001$
Sentence production	57% (8/14), grammatically correct, semantically incorrect argument selection	Controls performed at ceiling
Picture description	33%***(4/12), event comprehension errors	Controls performed at ceiling

*** $p < .001$.

The transitive verbs *hilbiš* ("dressed$_{\text{TRANSITIVE}}$" – dress someone) and *hic'id* ("marched$_{\text{TRANSITIVE}}$" – march someone) require an animage direct object – someone who is being dressed or marched. Both have alternants that also select a direct object, but, crucially, this direct object is of a different semantic nature: the DP complements of the alternants are inanimate objects – *lavaš* ("wear") takes a piece of clothing as a complement, and *ca'ad* ("march$_{\text{INTR}}$") can appear with a cognate object. We suggest that AL's errors with these two verbs, in which he produced a syntactically correct type of phrase as a complement (NP), but with a semantically non-matching DPs could be a result of his impairment in the conceptual system, and his intact syntactic lexicon. He produced a response matching the given verb with respect to the number of arguments and the subcategorization frame (i.e., all alternants select an DP complement), but the thematic/semantic role of the internal argument (i.e., whether it is animate or not) was incorrect.

This might be due to his impaired conceptual system, which prevents him from understanding basic semantic features of lexical items (see Appendix D for examples of AL's failure to grasp basic concepts in nouns and non-alternating verbs).

Finally, in the **picture description task**, AL made various conceptual errors. In some cases (36% of the items), his responses suggested that he did not understand the event depicted in the picture. For example, his response to a picture of a person paying the cashier in a store was: "They are holding something, a painting". When he was shown a picture of a hippo drying himself with a towel, and was asked "What is the hippo doing here?", the target response was the reflexive *mitnagev* or the transitive verb with a reflexive pronoun *menagev et acmo*. AL, however, said *menagvim im magevet* ("drying$_{\text{PLURAL}}$ with a towel"). He used the plural subject-agreement on the verb – suggesting he was either ascribing the agent role to a plural subject even though the hippo appeared alone in the picture, or was using an arbitrary subject (again, which indicates that the agent was different from the hippo). Again, his conceptual system yielded an event structure incompatible with the picture, but the sentence was grammatical. This is another way by which AL's difficulty with determining the number of arguments in an event affects the morphology of the verbs he uses.

4.1.1. Explaining the error pattern within the model

AL's conceptual impairment makes it difficult for him to know how many participants are in an event, and what their roles are. This affects the selection of an alternant in the syntactic lexicon, since the alternant is selected based on the thematic roles in the event. This also affects his knowledge about the roles of the arguments he selects (who did what to whom), and their animacy. Crucially, because AL's syntactic lexicon is intact (as well as the subsequent lexical retrieval stages), he uses the verbs he produces correctly in terms of their argument structure, even when he produces the incorrect alternant.

4.2. The semantic lexicon

In the model, we followed Biran and Friedmann (2012) in claiming that the lexical-syntactic information is stored in the syntactic lexicon rather than in the semantic lexicon. On a theoretical level, maintaining these two components separate is necessary for explaining why alternation errors occur in impairments to the syntactic lexicon: if semantic and argument structure representation of words occurred in a single stage, two alternants of the same verb would have been distinct and unrelated to each other from the beginning of the linguistic retrieval process, and therefore substitution of alternants would not have been expected when other substitutions are not present. In Section 4.3, we will present four patients, three of which do not have a deficit in the semantic lexicon, even though their syntactic lexicon was impaired. In this section we present evidence of the other side of the dissociation: a case of intact lexical-syntactic knowledge about argument structure of alternating verbs, with loss of semantic knowledge about these same verbs, both at the task level and at the individual verb level.

CN is a 61 year-old woman with primary progressive aphasia. She has an impairment in the semantic lexicon, deduced from her impaired naming and word comprehension and intact object knowledge, which rules out an impairment in the conceptual system. Table 5 summarizes the findings that led to this diagnosis.

To test CN's lexical-syntactic knowledge about argument structure, we used the grammaticality judgement task from the PASTA battery, which included 41 sentences, 22 grammatical sentences, and 19 ungrammatical sentences: 10 with alternant substitutions, and 9 with other argument structure violations. CN succeeded in judging correctly 40/41 of the sentences, and for one sentence she did not provide a response (an ungrammatical sentence with argument omission).

During the administration of the grammaticality judgement task, CN told us that she is judging the sentences without always understanding the meaning of the verbs. To test CN's knowledge about the meaning of alternating verbs, we asked her, one week after administering the grammaticality judgement task, to define 32 of the verbs from that same task. She was unable to correctly define 10 of these verbs, providing incorrect definitions or "don't know" responses, even though she had been able to correctly judge sentences that included the same verbs. Thus, upon receiving phonological input, CN can directly access the MOONs in the syntactic lexicon, without activating the meaning of the verb in the semantic lexicon. An example is given in (22).

(14) a. **Grammaticality judgement stimulus:**
dani hitgalgel et ha-kadur
Dani rolled$_{\text{INTRANSITIVE}}$ ACC the-ball.
Target response: ungrammatical.
Response: ungrammatical.
b. **Definition of the same verb:** hitgalgel (rolled$_{\text{INTRANSITIVE}}$)
Response: I don't remember, is it something about sharing?

CN's ability to judge argument structure violations (including alternant substitutions) even though she does not always know the meaning of the verbs that participate in these violations, demonstrates that argument structure is stored separately from meaning. This is expected from our model where the syntactic lexicon stores information about argument structure, and the semantic lexicon points to the verb's meaning.

4.3. The syntactic lexicon

For the description of the effect of a deficit in the syntactic lexicon on the production of sentences with alternating verbs we used data from patients who were diagnosed with a deficit in the syntactic lexicon in Biran and Friedmann (2012), and we also tested one of them (HY) with the HIFIL test battery. SN, RT, AO, and HY were tested with the PASTA test battery (Biran & Friedmann, 2009), which was not specifically designed to test verbal alternations, but included ample examples of alternating verbs. Patients' production was reanalyzed using the terms introduced in this paper. HY, who was tested with the PASTA battery in Biran and Friedmann (2012), was tested again with our HIFIL battery for alternating verbs, and her performance is described in Section 4.3.1. None of the patients had an impairment exclusive to the syntactic lexicon: SN had an additional deficit in the semantic lexicon, RT had agrammatism, AO had an impairment in the phonological output lexicon, and HY had agrammatism, and was also impaired in the phonological output lexicon, and the phonological output buffer. A detailed description of the diagnosis is found in Biran and Friedmann (2012). However, since they all show the same distinctive error pattern, and since their additional impairments are diverse, their error pattern can be attributed to a deficit in the syntactic lexicon.

In Biran and Friedmann (2012), patients were diagnosed with an impairment in the syntactic lexicon

Table 5. CN's performance in tasks that led to the diagnosis of an impairment in the semantic lexicon.

Task	% Correct and error types	Comparison to controls
Picture naming	29%*** Semantic errors, definitions	$M = 97\%$, SD = 2%, $N = 20$, $t(19) = 33.2$, $p < .001$
Word-picture matching	55%***	$M = 99\%$, SD = 2%, $N = 16$, $t(15) = 21.5$, $p < .001$
Picture-picture association	97%^{ns}	$M = 98\%$, SD = 3%, $N = 30$, $t(29) = 0.33$, $p = .38$

*** $p < .001$.

based on predicate argument structure errors, i.e., argument additions, omissions, and substitutions (e.g., substituting prepositions) in non-alternating verbs.

These errors are cases in which the patient produces a sentence with an incorrect number or type of arguments (in the sentence production task), selected a verb that does not match the number or types of arguments (in the multiple choice sentence completion task), judged a sentence with incorrect number or type of arguments as grammatical or judged it as ungrammatical but fixed it incorrectly, or alternatively when the patient judged a sentence with correct number and type of arguments as ungrammatical, while producing an ungrammatical sentence when attempting to correct it. Examples (14)-(16) present predicate-argument structure errors in the various tasks.

Examples for predicate argument structure errors

(15) **Sentence production to a given verb stimulus**: *tiken* (fixed$_{\text{TRANSITIVE}}$)

Response (AO, obligatory-argument omission): *Hu tiken mizman

*He fixed long-ago

(16) **Sentence completion stimulus**: *Ruti ____ b-a-gader.*

Ruti ____ into-the-fence

Options: *šatka* (was-silent), *banta* (built), *hitnagša* (bumped), *ra'ata* (saw)

Target response: *hitnagša* ("bumped")

Response (RT, argument substitution): *ra'ata* ('saw'), which requires a DP, rather than PP object, but is semantically compatible.

(17) **Grammaticality judgement stimulus**: *Dani he'evir.*

Dani passed (object arguments omitted)

Target response: Ungrammatical

Response (RT): Grammatical

The current model suggests that the syntactic lexicon is also responsible for the selection of alternant, which is represented in the model as selection of MOON (which in turn selects a STAR). Therefore it is predicted that the same patients who make predicate-argument structure errors will also make alternant substitution errors.

Alternant substitution errors are cases in which the patient used the argument structure of the other alternant (incorrect in the sentential context), or produced the other alternant altogether (in the sentence production task); selected a verb that does not match the number or types of arguments but matches its alternant (in sentence completion task); judged an ungrammatical sentence as grammatical in cases when replacing the verb with its alternant would have made the sentence grammatical; failed to fix ungrammatical sentences of this type or used the incorrect pattern when fixing it (in the grammaticality judgement task). Examples (17)–(19) present alternant substitution errors in the various tasks.

Examples for alternant substitution errors

(18) **Sentence production to a given verb stimulus**: *hiš'in* (leaned$_{\text{TRANSITIVE}}$).

Response (AO, argument omission): **hi hiš'ina al ha-xalon*

She leaned$_{\text{TRANSITIVE}}$ on the-window

'She leaned against the window'

(19) **Sentence production stimulus**: *hitlabeš* (dressed$_{\text{REFLEXIVE}}$).

Response (AO): *ha-iša lovešet simla xadaša*

The-woman wears$_{\text{TRANSITIVE}}$ dress new

'The woman is wearing a new dress'

(20) **Grammaticality judgement stimulus**: *ima histarka et dana*

Mom comb$_{\text{REFL}}$ ACC dana

'Mom combed-herself Dana'

Target Response: ungrammatical

Response (RT): grammatical

Our hypothesis was confirmed: we found that all patients with a deficit in the syntactic lexicon made both predicate-argument structure errors (argument omissions, additions, and substitutions), and alternant substitution errors, in at least two tasks. The percentage of each error type out of the total number of items, by patient and by task is presented in Table 6.

Importantly, RT and SN, who did not have an additional impairment in a phonological component, had errors in derivational morphology only in alternating verbs in the PASTA battery. They did not make any other errors in derivational morphology.

Table 6. Percent of Predicate Argument Structure (PAS) and Alternant Substitution errors (ALT) out of all items. Up to 9% of responses in each task were ambiguous and could be intepreted as either PAS or ALT errors, which we left out of the analysis.

	Sentence production		Sentence completion		Grammaticality judgement	
	PAS	ALT	PAS	ALT	PAS	ALT
SN	5%	0%	17%	6%	6%	3%
RT	13%	2%	26%	3%	8%	3%
AO	8%	6%	9%	0%	2%	11%
HY	11%	9%	34%	0%	17%	9%

4.3.1. HY – A case study of an impairment in the syntactic lexicon

HY is a 50 year-old woman who had an ischemic stroke involving left fronto-temporal areas. Her CT also revealed a hypodense area in the basal ganglia. As mentioned above, HY was tested also with two tasks from the HIFIL test battery. A summary of her performance in those tasks is presented in Table 7.

Table 7. HY's performance in the HIFIL test battery compared to controls.

Task	% Correct and error types	Comparison to controls
Sentence completion	16%*** (4/25), alternant substitutions	$M = 99.2\%$, SD = 1.7%, $N = 10$, $t(9) = 47.04$, $p < .001$
Sentence production	43%***, argument structure errors and alternant substitutions	Controls performed at ceiling

*** $p < .001$.

Her performance was similar to her performance in the PASTA battery, and to the performance of the other three patients with an impairment in the syntactic lexicon who were tested in the PASTA battery. That is, she made argument structure errors, as well as many alternation errors. In the sentence completion task she made alternant substitution errors in 44% of the items. In the sentence production task, she made argument structure errors in 32% of the items and alternation errors in 9% of the items. (20)-(21) are examples for HY's errors in the HIFIL test battery:

(21) **Sentence production stimulus**: *hikšiv* ('listened')
Response (HY, omission of selected preposition): **hu hikšiv harca'a.*
He listened lecture
(attempted: he listened **to** a lecture)

(22) **Sentence completion stimulus**:
Aya hidlika et ha-maxšev. Lakax l-a-maxšev kcat zman, aval b-a-sof hu ____.
Aya turned-on$_{\text{TR.F}}$ ACC the-computer$_{\text{M}}$. Took to-the-computer a-little time, but in-the-end he ____.
Aya turned on the computer. It took some time, but in the end it _____.
Target: *nidlak* (turned-on$_{\text{INTRANSITIVE.M}}$)
Response: *hidlik* (turned-on$_{\text{TRANSITIVE.M}}$)

4.3.2. Explaining the error pattern within the model

To recapitulate our finding regarding the syntactic lexicon: in addition to argument structure errors reported in Biran and Friedmann (2012), patients with an impairment in the syntactic lexicon also make errors with alternating verbs, which involve the morphological form of the verb (i.e., its pattern), and not only its selectional properties, using an incorrect alternant for the sentence.

When considering our model, it becomes clear why the two types of errors stem from the same syntactic-lexicon deficit: An impaired representation of argument structure in the syntactic lexicon may cause patients to add, omit, or substitute arguments. In the case of alternating verbs, where there are several options for argument structure (MOONs) for a single entry, the representations of the MOONs may be impaired (damaged/lost or inaccessible), and as a result, an incorrect argument structure may be used. Just as a patient can make a mistake in the argument structure of a non-alternating verb (e.g., **John bought*), they can also make the same type of error with an alternating verb (e.g., **John fell the vase*). Since for alternating verbs the selection of argument structure in the syntactic lexicon (MOON) affects the selection of the morphological pattern in the phonological lexicon (STAR), impaired MOON selection and argument structure errors in alternating verbs result in what look like morphological errors, even though the origin of these errors is not an impairment in morphological representation, but an impairment in lexical-syntactic information, which maps to morphological representation. When lexical-syntactic information is missing, correct mapping to morphological representation is not possible. Since the error is not in morphological representations themselves, morphological errors due to a deficit in the syntactic lexicon are confined to verbal pattern selection in alternating verbs, and do not occur in non-alternating verbs with similar patterns. SN and RT, who have a deficit in the syntactic lexicon but not in a phonological component, each made alternation errors, but they did not make any other morphological errors such as pattern substitutions in non-alternating verb or pseudo-alternating verbs.

4.4. The phonological output lexicon

HH and RR both have an impairment in accessing information in the phonological output lexicon, but their deficits crucially differ. HH's errors include hesitations, phonological errors, and semantic errors, but not morphological errors. RR has similar difficulty in word finding, but in addition to that he has errors in derivational morphology. Even when he is able to retrieve the correct root for the word, he sometimes selects the incorrect pattern (e.g., *colelet*, "submarine" → **colela*, both with the root CLL, but in a different nominal pattern). This pattern of impairment is markedly different than impairments in earlier stages of the model, since it occurs in all types of verbs and event in nouns, and is not specific to alternating verbs.

Table 8. HH's performance in tasks that led to the diagnosis of an impairment in access from the semantic lexicon to roots in the phonological lexicon.

Task	% Correct and error types	Comparison to controls
Picture naming	67%***, with frequency effect ($r = .22$, $p = .015$), no length effect. Phonological and semantic errors, hesitations, retrieving the target in English or providing a definition. No morphological errors.	$M = 96\%$, $SD = 2.6\%$, $N = 30$, $t(29) = 11.01$, $p < .001$
Word reading	No surface errors (100% correct), (no morphological errors either)	Surface errors: $M = 1.4\%$, $SD = 0.8\%$, $N = 1073$, $t(1072) = 1.79$, $p = .03$
"Spoonerism" task	$100\%^{ns}$	$M = 93.2\%$, $SD = 4.71$, $N = 18$, $t(17) = 1.31$, $p = .09$

*** $p < .001$.

Table 9. HH's performance in the HIFIL test battery compared to controls.

Task	% Correct	Comparison to controls
Sentence completion	$100\%^{ns}$	$M = 99.2\%$, $SD = 1.7\%$, $N = 10$, $t(9) = 0.45$, $p = .33$
Picture description	100%, but long hesitations	Controls performed at ceiling
Homograph reading	$97.5\%^{ns}$	$M = 97\%$, $SD = 4.2\%$, $t(9) = 0.1$, $p = .46$

In our model, following Friedmann et al. (2021) and Stark (2020) HH's impairment is modeled as difficulty accessing stems (roots), and RR's impairment is modeled as difficulty retrieving stems (roots) as well as accessing their STARs.

4.4.1. Impaired access to stems in the phonological output lexicon

HH is a 73 year-old man who was treated in a hospital following hemorrhagic stroke in the basal ganglia of the left hemisphere. His error pattern is typical of an impairment in the phonological output lexicon (or access to it from the semantic lexicon): he hesitates before retrieving some words, he avoids naming by using definitions and English words, and he makes phonological errors or uses semantically related words when he is unable to retrieve a word (e.g., *hošiva* – "sit$_{\text{TRANSITIVE}}$" → *henixa* "place$_{\text{TRANSITIVE}}$"; xagora – "belt" → *kagora). He does not have surface dyslexia, which shows that his phonological lexicon is intact, and his connection to the phonological lexicon from the orthographic lexicon is also intact. Therefore, his deficit is in the connection between the semantic lexicon and the phonological lexicon (Gvion & Friedmann, 2016). Table 8 summarizes the findings that led to his diagnosis.

In the analysis of HH's performance in alternating verbs as assessed using the HIFIL test battery (summarized in Table 9) we find that that he did not make morphological errors. In the picture description task, since the root is not provided by the experimenter in the stimulus (as opposed to the two other tasks), he hesitated a lot and his reaction times were long, as expected from a patient with difficulty retrieving roots. As predicted by the model, since HH does not have an impairment in access to the STARs, he did not make any morphological error in any of the tasks.

4.4.2. Impaired access to stems and STARs in the phonological output lexicon

RR is a 37 year-old man who was treated in a rehabilitation hospital following ischemic stroke in the M1 segment of MCA. RR was diagnosed with a deficit in the phonological output lexicon that affects both his access to the stems and his access to the STARs, according to the errors in derivational morphology he made in nouns and verbs. Table 10 summarizes the findings that led to his diagnosis.

RR's difficulty in the HIFIL test battery was mild but selective to derivational morphology. Table 11 summarizes his performance in the battery. His errors occurred both in alternating and in non- and pseudo-alternating verbs. RR made several morphological errors in the rephrasing task. For the target verb *hirkid* (dance$_{\text{TRANSITIVE}}$) his response was *hu hirkid, hu rakad, lo mešane, štehem oto davar* ("he danced$_{\text{TRANSITIVE}}$, he danced$_{\text{INSTRANSITIVE}}$, it doesn't matter, they are both the same"), and for the target verbs *hivlit* ("*emphasize*$_{\text{TRANSITIVE}}$") and *he'erix* ("lengthen$_{\text{TRANSITIVE}}$") his response was the intransitive

Table 10. RR's performance in tasks that led to the diagnosis of an impairment in roots and STARs in the phonological output lexicon.

Task	% Correct and error types	Comparison to controls
Picture naming	78%***, with frequency effect ($r = .02$, $p = .04$)	$M = 96\%$, SD = 2.6%, $N = 30$, $t(29) = 6.85$, $p < .001$
Morphologically complex word picture naming	57%***, morphological errors, semantic errors, definitions	$M = 93\%$, SD = 4.5%, $N = 30$, $t(29) = 7.87$, $p > .001$
Noun-verb and verb-noun derivation	78%, morphological (derivational) errors	

*** $p < .001$.

Table 11. RR's performance in the HIFIL test battery compared to controls.

Task	% Correct and error types	Comparison to controls
Sentence completion	100%^{ns}	$M = 97\%$, SD = 3.2%, $N = 21$, t (20) = .92, $p = .19$
Rephrasing	93.9%*, pattern substitution	$M = 98.6\%$, SD = 2%, $N = 19$, $t(18) = 2.3$, $p = .02$
Sentence production	94%* (16/17), pattern substitution	$M = 98.8\%$, SD = 2.4%, $N = 20$, $t(19) = 1.9$, $p = .04$
Multiple-choice sentence completion	98.1%^{ns}, pattern substitution	$M = 99.4\%$, SD = 1.2%, $N = 10$, $t(9) = 1$, $p = .16$

* $p < .05$.

alternants *balat* ("*emphasize*$_{\text{INTRANSITIVE}}$") and *arax* ("lengthen$_{\text{INTRANSITIVE}}$").[10] In the sentence production task, RR had one error (out of 17 attempted items) – when asked to produce a sentence with the word *hitraxec* (wash$_{\text{REFL}}$), he started with the transitive alternant (*raxax* – wash$_{\text{TRANSITIVE}}$), then he produced a verb with the CiCeC pattern, which is not available for this root (**rixec*), and finally he produced the target verb. RR had one error in the multiple choice sentence completion task (1/54), and it was with a pseudo-alternating verb: when the target was *hištalma* ("be worthwhile"), his response was *šilma* ("pay"), but he later corrected this error. In a word derivation task (GZIRIM, Stark et al., 2018) RR had pattern errors with non-alternating verbs: he produced **kofterim* for *mekafterim* ("(to) button") and **mekadxim* for *kodxim* ("(to) drill").

4.4.3. Explaining the error pattern within the model

HH's deficit is in accessing stems in the phonological lexicon, not in accessing the STARs, and therefore, he does not make any morphological errors, as predicted by the model. RR, on the other hand, made errors with alternating, pseudo-alternating, non-alternating verbs, and also nouns, as predicted by the model. Crucially, his morphological errors are not selective to alternating verbs (unlike impairment in the syntactic lexicon), since their source is not argument structure but rather phonological representation. The errors resulted in existing verbs in some cases, and in non-existing root and pattern combinations in others. RR's morphological errors are derivational errors, since derivational morphology, unlike predictable inflectional morphology, is listed in the STARs in the phonological output lexicon. RR's errors can be explained by his impairment in access to the STARs of the phonological output lexicon: In all of his errors, even when he was able to access the correct root (which was also given to him in the stimulus), he had difficulty accessing the correct STAR (due to impairment in their storage, accessing them from the lexicons, or accessing the corresponding phonological realization at a later stage), resulting in pattern substitutions.

4.5. The phonological output buffer

For the pattern of impairment in the phonological output buffer we describe results from nine participants with an impairment in this component due to aphasia. We present additional 6 participants with phonological output buffer impairment due to thiamine deficiency in infancy in Appendix E. Patients were diagnosed with an impairment in the phonological output buffer based on impaired non-word repetition and non-word reading. An impairment in the phonological output buffer is manifested in errors in reading and repetition, particularly in nonwords (Caramazza et al., 1986), involving both phonological and morphological error types (Guggenheim, 2015). Table 12 summarizes the results of each participant in these two tasks.

For the assessment of alternating verbs, all nine patients were tested in the sentence completion task of the HIFIL test battery. Their performance is summarized in Table 13. Each of the patients with

Table 12. Performance (%correct) in nonword repetition and reading that led to the diagnosis of an impairment in the phonological output buffer.

Participant	Nonword repetition (48 items)	Nonword reading (40 items)
SH	50%	56%
VV	38%	49%
AV	81%	20%
SK	60%	44%
EL	38%	44%
DL	58%	60%
UB	76%	71%
BG	85%	90%
AG	81%	90%
Controls	*N* = 20, *M* = 95.5%, SD = 3.5%	*N* = 1073, *M* = 94.2%, SD = 7.2%

Shaded cells indicate significantly higher error rate compared to controls.

an impairment in the phonological output buffer showed difficulty with both derivational inflectional morphology: They produced verbs with incorrect derivational morphology patterns (either substituting alternants or using a different pattern), and incorrect inflectional morphology (using incorrect tense and agreement marking on verbs).

All participants had more alternant substitutions or pattern substitutions than the control's average, and all participants had more tense or agreement errors than the control's average. The percentage of morphological errors for each participant and error type is shown in Table 13.

The association between errors in derivational and inflectional morphology in phonological output buffer impairments is consistent with Dotan and Friedmann (2015), who found a general morphological deficit in patients with a selective impairment in the phonological output buffer. This is dissociated from other patients presented in this paper who either had a selective deficit in derivational morphology, or an even more selective morphological deficit affecting only alternating verbs, with no other morphological errors.

4.5.1. SH – A Case study of an impairment in the phonological output buffer

SH is a 23 year-old woman who was treated in a rehabilitation hospital following hemorrhagic stroke in fronto-parietal regions of her left hemisphere. She was diagnosed with a deficit in the phonological output buffer based on her performance in nonword repetition and reading aloud (see Table 12) as well as morphological errors in reading morphologically-complex nouns and verbs. Since she was tested with a wider battery of tasks, she is presented as a case study. She showed the same pattern of impairment as the other patients with a deficit in the phonological buffer, that is, she made errors with derivational and inflectional morphology (see Table 13). Within derivational morphology, SH made derivational errors not only in alternating verbs, but also other kinds of derivational morphology.

In the sentence completion task, she produced correct responses in only two of the 48 items. In the rest of the items, she showed great difficulty producing the correct verb form, with several unsuccessful attempts in most items. SH seemed to notice that she did not produce the correct form, as she kept

Table 13. Different error types for participants with a phonological output buffer deficit (% of total verbs produced).

	Derivation		Inflection	
Participant	Alternant substitution	Pattern substitution	Tense error	Agreement error
SH	56%	38%	17%	2%
VV	17%	3%	0%	3%
AV	26%	11%	11%	12%
SK	37%	3%	3%	0%
EL	10%	15%	4%	6%
DL	13%	0%	7%	0%
UB	5%	0%	0%	7%
BG	2%	0%	8%	5%
AG	29%	3%	17%	6%
Controls (age 20–29) *N* = 21	*M* = 1%, SD = 1.6%	*M* = 0.2% SD = 0.6%	*M* = 0.6% SD = 1.2%	*M* = 0.2% SD = 0.6%
Controls (age 50–66) *N* = 10	*M* = 0.2% SD = 0.7%	*M* = 0% SD = 0%	*M* = 0% SD = 0%	*M* = 0.2% SD = 0.7%

Shaded cells indicate significantly higher error rate compared to the control group; When the relevant control group performed at ceiling for a given error type, and no statistical comparison was possible, a single error of that type was considered significant.

Table 14. SH's performance in the HIFIL test battery compared to controls.

Task	% Correct	Comparison to controls
Sentence completion	4.2%(***), pattern substitutions and inflectional errors	$M = 97.7\%$, SD = 1.9%, $N = 21$, $t(20) = 48.1$, $p < .001$
Rephrasing	60%(***) (3/5), pattern substitutions	$M = 95.8\%$, SD = 8.1%, $N = 19$, $t(18) = 6.7$, $p < .001$
Sentence production	21%(***) (7/33), pattern substitutions and inflectional errors	$M = 99.5\%$, SD = 1.5%, $N = 20$, $t(19) = 50.3$, $p < .001$
Multiple-choice sentence completion	56%(***) (10/18), pattern substitutions	$M = 99.4\%$, SD = 1.8%, $N = 10$, $t(9) = 23.8$, $p < .001$

(***) $p < .001$.

trying after unsuccessful attempts (suggesting that her phonological input pathways were intact). Just as the results showed for the entire group of individuals with an impaired phonological output buffer, SH had many errors in the verbalderivational morphology. Her most common error type was alternant substitution, followed by pattern substitution. Some of her pattern substitution errors resulted in an existing verb (e.g., *mesareket* "comb$_{\text{TRANSITIVE}}$" → *sorek* "scan") or an existing noun (*hit'aper* "apply makeup$_{\text{REFLEXIVE}}$" *ipur* "makeup"), and some resulted in a non-existing combination of root and pattern (*mesabnim* – "soap$_{\text{TRANSITIVE}}$" → **sovnim*). SH also made many errors inflectional morphology. She made agreement errors in 25% of the items, and tense errors in 21% of the items (e.g., *da'ag* "worried" → "*do'eg*" – "worries"). Finally, SH also made phonological errors in root consonants in 19% of the verbs (e.g., *coxek* – "laugh$_{\text{INTRANSITIVE}}$" → **coxex*, *mitragšim* – "be excited" → **mitgašim*).

As expected, SH had morphological errors not only with alternating verbs, but with non- and pseudo-alternating verbs as well: In the sentence production task, in addition to alternant substitutions, SH had a morphological error with a pseudo-alternating verb: when asked to use the word *hitganev* (sneak) in a sentence, SH produced the sentence *mišehu ganav* – "someone stole". In the multiple choice sentence completion task, SH tended to select the incorrect alternant for alternating pairs and, in two cases, she also selected the incorrect verbal pattern for pseudo-alternating pairs: *bitla* – "cancel$_{\text{TRANSITIVE}}$" instead of *hitbatla* – "be lazy" (a "double agent" in a non-alternating context), and *šilma* – "pay", instead of *hištalma* – "be worthwhile". In the verb picture naming task, SH made alternant substitutions (31%), agreement errors (19%), tense errors (15%), and pattern substitutions (11.5%). In this task, as well as in other tasks, SH made pattern substitutions that resulted in cross-category change. That is, she used nominal or adjectival pattern instead of a verbal pattern. For example when she attempted to retrieve the verb *mit'aperet* ("apply-makeup$_{\text{REFL}}$"), her response was *af..afer..afor..afur..apir.* All of SH's attempts in this item were non-words and words in nominal and adjectival patterns. Later she produced the nominal *ipur* ("makeup$_{\text{NOUN}}$") after a phonological cue (the first syllable), but she failed to produce the reflexive verb *mitaperet*.

In conclusion, SH's errors in morphology are consistent with other patients with a similar deficit, and with the role of the phonological buffer in the production of verbal morphology we propose in the model. Table 14 summarizes SH's performance in the HIFIL test battery.

4.5.2. Explaining the error pattern of POB patients within the model

The error pattern presented by the participants with an impaired phonological output buffer is predicted by the model. The participants were diagnosed with an impaired phonological output buffer mainly based on their phonological abilities (e.g., impaired repetition and reading aloud of nonwords; limited phonological spans). All of them made morphological substitutions as well: they all substitute derivational morphemes (patterns), which could result in the alternant, in another non-alternating verb with the same root, in a non-existing verb, or in a noun or an adjective. All of them also substitute inflectional morphology – tense and agreement inflection. This is consistent with Dotan and Friedmann's (2015) proposal that the phonological output buffer has access to a morphological mini-store that stores preassembled inflectional and derivational morphemes as whole units. The current results suggest this is true for a variety of morphemes, which the phonological buffer receives as input from different sources: agreement comes from the syntax (a relation between the verb and the subject, or a dedicated agreement head), and is purely formal. Tense also comes from syntax (T head), and contributes to the meaning of the sentence in a predictable way, so it is also rooted in the conceptual selection. Verbal patterns, we suggest, are abstractly represented in the phonological output lexicon under each stem/root. They contribute to the meaning of the sentence, but their meaning in the context of a specific root is idiosyncratic to some extent. For the phonological output buffer, it seems, the origin of the morpheme does not matter – all morphological affixes (patterns, nominal templates, inflectional affixes) are stored as whole units in dedicated long-term memory stores, and are assembled with the stem before production. A deficit in the phonological output buffer causes these morphemes to be substituted with each other, added, or omitted.

5. Discussion

The goal of this study was to design a neuropsychological model that can account for lexical retrieval within a sentence context. Lexical items are almost always produced in a sentential context and not in isolation. Therefore, theories of lexical retrieval must play a central part in theories of sentence production, and vice versa. We started with a model for lexical retrieval, and expanded it to account for the retrieval of alternating verbs with their correct argument structure and the matching morphological manifestations in Hebrew. Verbal alternations are at the interface between single words and sentence-level considerations, since their morphology is tightly linked to their argument structure. The model we propose can account for the different error patterns of patients with impairments in different stages of the process, and can explain why what seems like morphological errors on the surface can stem from deficits in components that are not usually considered as responsible for morphology (the conceptual system, the syntactic lexicon, the phonological output lexicon) as well as components that were previously linked to morphology (the phonological output buffer). The findings are summarized in Figure 5.

The proposed model is similar to models of lexical retrieval of single words (e.g., Butterworth, 1989; Nickels, 1997), with minimal additions that had to be made in order to expand it to account for alternating verbs within sentences. We depended on three previous proposals in the study of the lexical retrieval model: (1) The proposal that the syntactic lexicon, which stores information about argument structure is separate from the semantic lexicon and that representations of argument structure are separate from semantic representations (Biran & Friedmann, 2012). (2) The proposal that entries in the phonological lexicon have a complex structure in which several compatible affixes are listed under a single stem (Friedmann et al., 2021). (3) The finding that the phonological output buffer is not only responsible for phonological assembly and activation, but also for morphological assembly and for storage of pre-assembled phonological forms of affixes (Dotan & Friedmann, 2015). From there, all is left is to connect the dots: One item in the semantic lexicon corresponds to several argument structures in the syntactic lexicon, each corresponding to the same stem, but a different verbal pattern in the phonological lexicon. The phonological buffer then assembles the stem and the selected pattern for production. This is a completely automatic and deterministic process. But, how is the selection of a specific entry in the syntactic lexicon determined? The simplest explanation, we think, is that this is determined by the speaker's intention, what their message is intended to convey, and on which aspects it focuses. Every sentence begins with an idea. This is represented in some non-linguistic manner in the conceptual system of the speaker.

Our model is grounded in existing linguistic and neuropsychological literature. One innovation of our suggested model is the proposal regarding the way the alternants are related and the way their argument structure is determined: we suggest that the syntactic lexicon includes MOONs, sub-entries which are related to the abstract event. Each verb may be represented with several MOONs in the syntactic lexicon, each representing a different argument structure. It is not a new idea that the initial selection of a verb is underspecified for some syntax-related information such as argument structure. This had been explicitly proposed by Biran and Friedmann (2012) and was previously also found in some understandings of the term *lemma* (Bock & Levelt, 1994; Levelt, 1989; Levelt et al., 1999, among others). However, in previous accounts, the semantic lexicon, although containing abstract information, is anchored to a single phonological representation of the entry. That

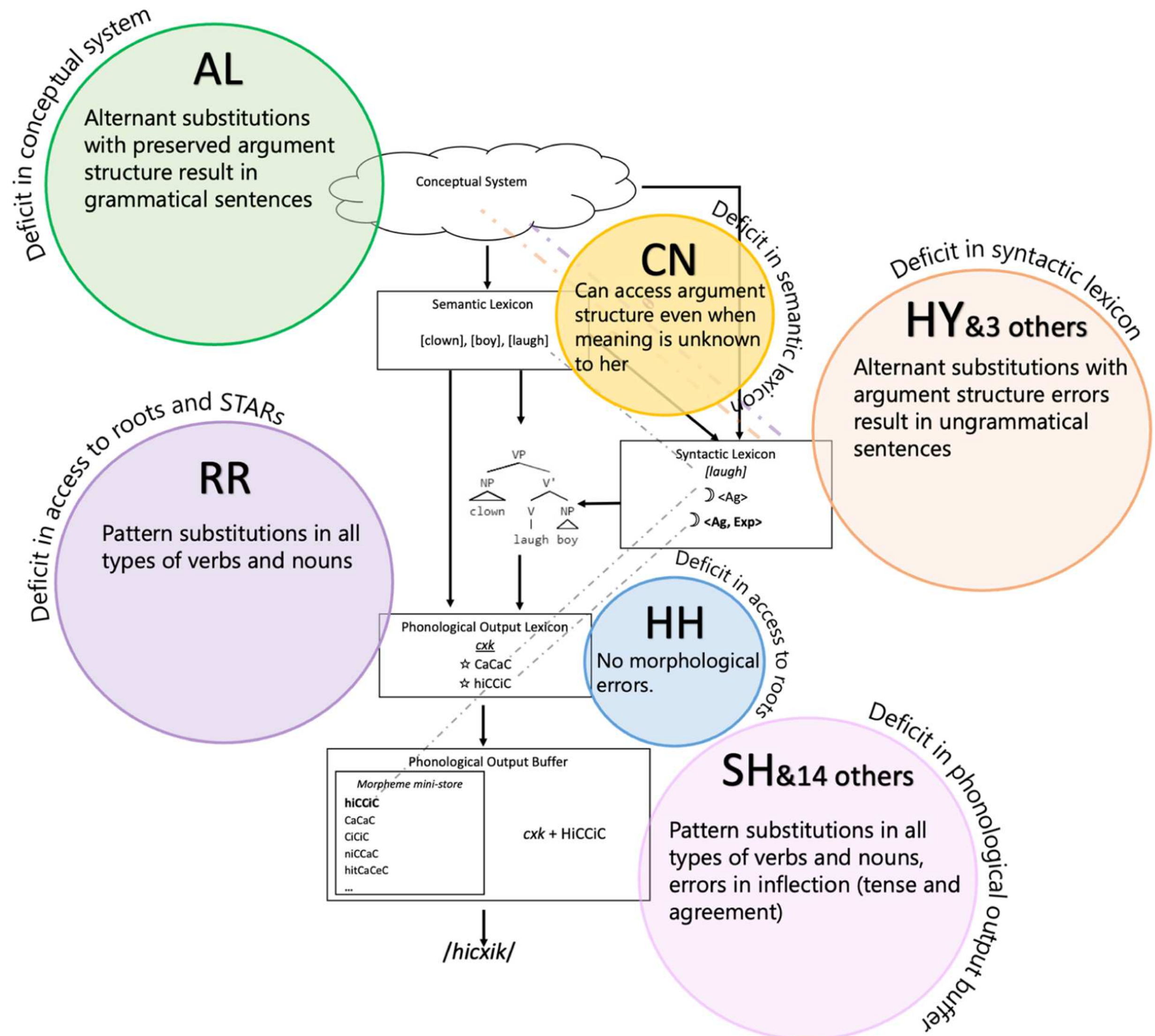

Figure 5. A summary of the results. Each bubble represents a patient or a group of patients with a deficit in a specific component. AL has a deficit in the conceptual system, HY and three other patients have a deficit in the syntactic lexicon, RR has a deficit in accessing roots and STARs in the phonological output lexicon, HH has a deficit in accessing roots in the phonological output lexicon, and SH and 14 other patients have a deficit in the phonological output buffer The text in the bubble summarizes their error pattern with morphologically-complex verbs within sentences.

is, there is usually a 1:1 correspondence between abstract entries in the semantic lexicon and their phonological representations. Therefore, alternating verbs in such models would have to be derived by two different entries in the semantic lexicon, each with its own argument structure specifications, and each connected to a different phonological form. Empirically, our study showed that this is not the case: some patients have a deficit that selectively affects alternating verbs and causes substitution between the two alternants. This finding indicates that the two alternants share a representation at some stage, and it is not the case that they are entirely separate words. We conclude that an entry in the semantic lexicon can correspond to several subentries in the phonological lexicon, through several subentries in the syntactic lexicon.

5.1. Theoretical and clinical implications

The current model has theoretical as well as clinical implications. For neuropsychological theory, our model can more accurately capture the essence of the phenomenon it describes: speaking is not about uttering a list of unrelated words, but about complex utterances in which individual items depend on others in form and in meaning, like alternating verbs, which depend on the arguments in the sentence. This enables a more accurate theoretical representation of language, better ecological validity, and a more fruitful dialog between cognitive neuropsychology and theoretical linguistics.

Future work should also study verbal alternations in other languages and additional phenomena that involve lexical retrieval, the sub-word level, and sentence-level considerations. This requires carefully accounting for similarities and differences between languages and linguistic phenomena that might seem underlyingly similar. It is reasonable to predict that Arabic and other Semitic languages with a similar root and pattern morphology will present similar types of impairment, and follow the same architecture of the model we proposed here. We conjecture that even in languages in which alternants are homophones (e.g., English and Dutch, as in "John closed the window" vs. "the window closed") the abstract representations (MOONs) are similar to the ones suggested in our model for Hebrew (two alternative argument structures), but the phonological realization in the phonological lexicon is constant (no affix). However, we currently have no empirical data from languages with different properties of alternations, therefore it is still an open question how an impairment in alternating verbs will surface in such languages. Testing bilingual patients with a deficit in alternating verbs who speak Hebrew and English (or a similar language with no morphological marking on alternations) is likely to shed light on this interesting and open question.

With respect to clinical implications, our results show that there are diverse impairments that can give rise to errors that look like morphological errors, each with its own characteristic error pattern on different types of words and morphemes. The test battery we designed can be used to identify the error pattern and to locate the functional deficits that cause them within our model. As for implications on treatment, the presence of an organizing theory of subtypes of morphological impairments and a battery designed to diagnose them can assist diagnosis and personalized treatment for patients with morphological errors.

Notes

1. Causative alternations are sometimes further divided into the transitive-unaccusative alternation ("close", as in 1a, b), the causative alternation ("walk", *The dog walked; The girl walked the dog*), and the experiencer alternation ("worry", *Moise worried; The lockdown worried Moise*). See Horvath and Siloni (2011), Levin and Rappaport Hovav (1995), Reinhart (2000), among others for detailed descriptions and differentiation of transitivity alternations in Hebrew and other languages.
2. There are two additional passive patterns that are traditionally considered *binyanim*, CuCaC and huCCaC. However, we will not discuss them in the context of verbal alternations, since, unlike the other pattern alternations, their form and distribution are almost completely regular, predictable, and productive: CuCaC is the passive form of verbs in CiCeC, and huCCaC is the passive form of verbs in hiCCiC. In this sense, passive formation in CuCaC and huCCaC resembles inflection: the output form depends on the pattern of the active form (which is, at least to some extent, idiosyncratic), but given an active form in CiCeC and hiCCiC, the passive form is almost completely regular, productive and predictable (see Laks, 2014a, 2014b, for experimental evidence). This is in contrast to the unpredictable morphology of alternating verbs, as discussed in this paper.
3. Examples with Hebrew verbs are given in the citation form, masculine singular in the past tense.
4. Although there have been attempts to find generalizations about form-meaning-syntax correspondence for patterns, e.g., Doron (2003), Kastner (2020).
5. This shared meaning component is difficult to formulate and is not regular. For example, even though *hištalem* ("be worthwhile", "pay off") is somehow related in meaning to *šilem* ("pay"), as can also be seen by the similarity of the verbs in the English translation, it is not the case one is the causative or the reflexive of the other. The evasiveness of the meaning of the Semitic root, which can appear in different patterns and retain some core meaning difficult to formulate, had been extensively studied (Arad, 2005; Aronoff, 1993; Panagiotidis, 2020). Since the extent to which a meaning is shared between two verbs with the same root is difficult to assess, we call all pairs of verbs that share a root but are not derivationally related (i.e., they do not participate in a "grammatical" alternation) "pseudo-alternating verbs", whether they have shared meaning or not. Whenever there is a shared meaning, we attribute it to the root, and not to a derivational relation between the two verbs.
6. Only the number of participants, without their role, is insufficient for selecting the correct alternant in some cases. Consider for example the experiencer alternation (e.g., paxad-hifxid – "fear"-"frighten"), in which bothalternants have two arguments each. In this case, the role of the internal argument, which is different (Reinhart, 2000), determines with alternant the speaker selects.
7. Our model does not differentiate between impairment in access to STARs and impairment to representations

themselves. In what follows, we will refer to both as "impairment in access to STARs", since impaired storage entails inability to access the representation. A possible prediction could be that patients with a deficit in storage would consistently be unable to retrieve specific lexical items, as proposed by Howard (1995) for word representations in the phonological lexicon, whereas an access deficit will be manifested by inconsistent errors.

8. For example, *he'ir* could either mean "wake-up$_{\text{TRANSITIVE}}$", alternating with *hit'orer* ("wake-up$_{\text{INTRANSTIVE}}$") or it could mean 'to comment', a non-alternating verb.
9. See Sauerland and Alexiadou (2020) for a specific account of hierarchical representations in the conceptual system within theoretical linguistics. Guasti et al. (2023) suggest that this account can be compatible with language production models, and points to the conceptual system as the locus of hierarchical conceptual representations.
10. In the case of *hivlit* ("emphasize") an *he'erix* ("lengthen") RR selected an incorrect alternant that was not presented in the lead-in sentence. These are cases in which one abstract verb has three alternants. RR made an additional, morpho-phonological errors: *hivhir* ("clarify$_{\text{TRANSITIVE}}$") → **hibhir*. *v* alternates with *b* in post-vocalic positions in Hebrew (spirantization). The control group made no similar errors. Additional investigation of this type of errors could potentially hint to the locus of application of the spirantization rule in Hebrew, and how its environment is represented by the grammar (i.e., by searching for a preceding vowel, or by generalizing over patterns).
11. We use the experiencer role instead of a theme in causatives with an unergative alternant based on Horvath and Siloni's (2011) proposal that during causativization the Agent of the unergative verb loses its [+c] feature, but retains its [+m] feature, making it [-c+m] - an experiencer in Reinhart's theta system, as opposed to a theme [-c-m] (Reinhart, 2000). This is not a necessary distinction in the model, but it does provide a simple explanation of how alternants like lavaŝ ('wear') and hilbiŝ ("dress$_{\text{TRANSITIVE}}$") are distinguished by the speaker, even though both can surface as two-place predicates (e.g., Mary wears a shirt, Marry dresses John) – if in the first case the agent is a theme and in the second it is an experiencer, there is a difference in their argument structure, and therefore they can be distinguished. A possible alternative is that since hilbiŝ ("dress$_{\text{TRANSITIVE}}$") is ditransitive in Hebrew, the second complement is represented at some level even when it does not surface. This additional argument makes the two verbs distinguishable.
12. Nouns like 'clown' and 'boy' may also appear under STARs, since they have a root and a nominal template. We do not elaborate on this since this paper is about verbs, the representation of nouns in the phonological lexicon is very similar to that of verbs, see Stark (2020) for empirical evidence.

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Appendices

Appendix A: An example for the production of an alternating verb: from event structure to verbal pattern

As an example of the cascaded process of the production of a sentence with an alternating verb, we will now show the derivation of the alternating verb *hicxik* ('laugh$_{\text{TRANSITIVE}}$', 'make someone laugh'), in the sentence *ha-leican hicxik et ha-yeled* ('the clown made the boy laugh'). The derivation starts with an idea at the conceptual system. The conceptual representation includes some representation of a boy laughing, with a clown causing it. In the next stage, if the speaker wants to produce a sentence that corresponds to the idea, the abstract forms of the relevant lexical items are numerated in the semantic lexicon. The items are [laugh], [boy], and [clown] (we ignore definiteness, tense, or any functional material that might originate at this stage). Items in the semantic lexicon do not have lexical-syntactic or phonological features, but are merely pointers to their representations in other lexicons. The item [laugh] denotes the event of laughing, and corresponds to both the intransitive and the transitive alternants. Next, the entry [laugh] is accessed in the syntactic lexicon. There are two MOONs under the entry: ☽<Ag>, and ☽<Ag,Exp>.[11] ☽<Ag,Ex*p* > is selected based on the conceptualization of the event, which includes two participants, an agent, and an experiencer. The syntactic component builds the hierarchical syntactic structure in which the agent is mapped externally to the VP and the experiencer is mapped internally to the VP. The next stage is phonological realization, the abstract lexical items from the terminal nodes in the structure are mapped to their form by the phonological lexicon: [clown] and [boy] receive a phonological realization by the activation from the semantic lexicon (*leican* and *yeled* respectively[12]), and the verb receives phonological realization that is pointed to by the semantic and syntactic lexicons in the following way: the semantic lexicon activates the verb stem CXK in the phonological lexicon, which has two STARs ☆CaCaC, and ☆hiCCiC. The transitive MOON in the syntactic lexicon (☽<Ag,Exp>) activates ☆hiCCiC. Finally, the stem activates the root phonemes CXK in the phonological output buffer, and ☆hiCCiC activates the phonological form of the hiCCiC pattern in the morphological mini-store in the phonological output buffer. The stem and the pattern are assembled, and the verb is ready to be produced. The words are produced in an order determined by the hierarchical output of the syntax, and possibly by a component responsible for its linearization, which may or may not be the phonological output buffer itself. A sketch of this derivation is presented in Figure 3 in the main text.

Appendix B: Demographics of control groups

All participants in the control groups had at least 12 years of education, and each control group included both males and females. Table B1 provides information about the control groups and the age ranges of the control participants for each task in the HIFIL test battery. HH was significantly older than the control group, and nonetheless his performance was not significantly different from controls. RR was significantly older than the younger control group and significantly younger than the older control group. He was compared to the control group that performed lower, and on the tasks in which he was impaired, he performed worse than both control groups.

Table B1. Age of controls in the HIFIL test battery.

<table>
<tr><th>Task</th><th>Age group 1 (20–33)</th><th>Age group 2 (50–66)</th></tr>
<tr><td>Sentence completion</td><td>20–29 (M = 24.1, SD = 2.6, N = 21)</td><td>50–66 (M = 59.7, SD = 4.5, N = 10)</td></tr>
<tr><td>Rephrasing</td><td>22–33 (M = 25.4, SD = 3.4, N = 17)</td><td>50–66 (M = 59.4, SD = 4.5, N = 10)</td></tr>
<tr><td>Sentence production</td><td>20–31 (M = 25.4, SD = 2.8, N = 15)</td><td>50–66 (M = 59.6, SD = 4.5, N = 10)</td></tr>
<tr><td>Picture description</td><td>22–33 (M = 25.9, SD = 3.3, N = 14)</td><td>50–66 (M = 59.6, SD = 4.6, N = 10)</td></tr>
<tr><td>Multiple choice</td><td colspan="2">22–42 (M = 28.2, SD = 6.3, N = 10)</td></tr>
<tr><td>Reading</td><td colspan="2">21–60 (M = 28.2, SD = 11.4, N = 9)</td></tr>
</table>

Appendix C: Stimuli in the HIFIL test battery

Task 1: Sentence completion

Table C1. Types of verb alternations included in the sentence completion with various patterns task.

Verb type	Example	# Items
Unaccusative-Transitive	*nafal-hipil*—"fall-drop"	6 × 2
Unergative-Transitive	*ca'ad-hic'id*—"march"	6 × 2
Subject experiencer-Object experiencer	*da'ag-hid'ig*—"worry"	6 × 2
Reflexive-Transitive	*hitraxec-raxac*—"shower"	6 × 2

In each sentence, the stimulus and the target also differ in inflection (tense or agreement marking), to test inflectional morphology, and to verify that when participants use the incorrect alternant, they do not simply repeat the given stimulus alternant. For each verb type, three of the transitive alternants appear in the task before their intransitive alternants, and three of the intransitive alternants appear before their intransitive alternants, to prevent bias for verb type. Each condition contains diverse pairs of patterns (e.g., in the transitive-unaccusative alternation there were items in which the unaccusative alternant was in hitCaCeC and the causative alternant in CiCeC, and items in which the unaccusative alternant was in CaCaC and the causative alternant was in hiCCiC).

Task 2: Rephrasing

Table C2. Verbs in the sentence completion with various patterns task.

Pattern combination	Example	# items
CaCaC-hiCCiC	*rakad-hirkid*—"dance"	5
CaCaC-CiCeC	*samax-sime'ax*—"be/make happy"	1
niCCaC-hiCCiC	*nidbak-hidbik*—"stick, infect"	5
niCCaC-CaCaC	*nisgar-sagar*—"close"	5
niCCaC-CiCeC	*nirpa-ripe*—"cure"	1
hitCaCeC-hiCCiC	*hitbaher-hivhir*—"clear"	5
hitCaCeC-CiCeC	*hitxamem-ximem*—"warm"	5
hitCaCeC-CiCeC with quadrilateral roots	*hitbalbel-bilbel*—"confuse"	5
hitCaCeC-CiCeC with bilateral roots	*hitmotet-motet*—"collapse"	5
hiCCiC-hiCCiC	*hilbin-hilbin*—"whiten"	5
Reflexives in hitCaCeC	*sirek-histarek*—"comb"	5
Reflexives in niCCaC	*rašam-niršam*—"sign up"	2

Task 3: Sentence production to a given verb

Table C3. Verbs in the sentence production to a given verb task.

Verb type	Example	# items
Unaccusative-Transitive	*nidlak-hidlik*—"turn on"	4 × 2
Unergative-Transitive	*ca'ad-hic'id*—"march"	4 × 2
Reflexive-Transitive	*hitgal'ax-gile'ax*—"shave"	8 × 2
Pseudo-alternating	*xalam/hexlim*—"dream'/'heal"	8 × 2
Non-alternating hiCCiC	*hiklid*—'"ype"	8

For each alternation, 4 of the transitive alternants appear before their intransitive alternants, and 4 of the intransitive alternants appear before their transitive alternants in order to prevent bias for verb type.

Task 4: Multiple choice sentence completion

Table C4. Verbs in the sentence production to a given verb task.

Verb type	Example	# Items
Unaccusative-Transitive	*nidlak-hidlik*—"turn on"	8 × 2
Unergative-Transitive	*ca'ad-hic'id*—"march"	8 × 2
Reflexive-Transitive	*hitgal'ax-gile'ax*—"shave"	1 × 2
Pseudo-alternating	*xalam/hexlim*—"dream'/'heal"	9 × 2
Double agents	*he'ir*—"wake up/comment"	4

Task 5: Picture description

Table C5. Verbs in the picture description task.

Verb type	Example	# Items
Transitive (with alternating unaccusative)	*hidlik*—"turn on"	4
Transitive (with alternating unergative)	*hirkid*—"make dance"	4
Reflexive	*hitkale'ax*—"shower"	4
Pseudo-alternating	*xalam*—"dream"(*hexlim*—'heal')	4

Appendix D: Individual patient information and diagnosis

The conceptual system

AL is a 69 year-old man who was treated in a rehabilitation hospital following a stroke that involved his left temporo-occipital region. We concluded that AL has an impairment in the conceptual system on the basis of his performance in the following tests:

(1) In a picture naming task (SHEMESH, Biran & Friedmann, 2004), he had errors in 100% of the items, in 40% of them he had unrelated errors and his other errors were semantic errors oruse of definitions. E.g., when he was shown a picture of a pomegranate, a widely recognized and culturally prominent fruit in Israel, his response was “It’s a cup, to drink juice out of a plate. Here it is cut, so we can see what it is, but it’s a cup of juice. You can eat it”. When he was shown a picture of an axe, his response was: “It’s terrible, I know what it is, but I don’t know how to say what it is. You prepare it when you want to cut something or to straighten something in the food. Or after [eating] the food.” And when he was presented with a picture of a lock, his response was “It’s a chain. Is it a chain? It’s not a chain, but a thing to answer to people on the telephone. It’s a telephone”.

(2) Picture association can distinguish between a deficit in the semantic lexicon, affecting only language, and a deficit in the conceptual system which is non-modal. In this task (Biran & Friedmann, 2007) the participant is presented with a picture and two additional pictures: a picture semantically associated with the first picture, and a distractor. The participant is asked to choose the picture that is associated with the first picture. Individuals with impaired conceptual system make errors in this task, whereas those with only a deficit in the semantic lexicon do not. AL had 17% errors. E.g., when presented with a picture of a soup bowl, a fork and a knife, AL chose the knife as associated with the picture of a bowl. When presented with a picture of a tea cup, he chose a picture of a tomato as associated with it, instead of a picture of a lemon. When presented with a picture of a cow, he chose a picture of a Coca-Cola bottle instead of a picture of a milk carton. Since AL had difficulty in this task, which does not involve language, we concluded that his impairment is not restricted to language, but rather also involves his conceptual system.

(3) To rule out an alternative explanation according to which AL’s deficit in picture naming and picture association was due to a visual impairment, we administered naming to definitions task. For the definition: “An electric device where food is stored so it won’t go bad” AL’s response was “a plate”, for the definition “the opposite of late” his response was “close”, for the definition “A body organ that enables us to see” his response was “glasses”, and for the definition “A body organ used for walking” his response was “pants”. Overall, AL performed very poorly in this task. In the latest occasion he was tested with this task, he was able to immediately name the target word correctly in only 25% of the items. Namely, he makes semantic errors not only when the input is visual, but also when it is auditory.

AL also showed difficulty in syntactic tasks, specifically in the production and comprehension of sentences with syntactic movement. In a shortened version of a sentence production task (ADIF, BAMBI battery, Friedmann & Novogrodsky, 2002; Friedmann & Szterman, 2006; Novogrodsky & Friedmann, 2006) and a production task using pictures (ZIBUV, BAFLA battery, Friedmann, 1998) AL made errors with object relatives but not subject relatives (0/3 and 3/3 correct respectively). In a sentence-picture matching task (ZST-TLAT, Friedmann & Novogrodsky, 2011; Friedmann & Szterman, 2011), AL made role substitution errors, mostly with object questions and object relatives, but also with subject relative clauses and, crucially, simple SVO sentences (total of 13/26 correct across all sentence types). For example, for the simple stimulus sentence “This giraffe licks the cow”, AL pointed at the picture of the giraffe that is licked by the cow, rather than the one that licks the cow. Difficulty with sentences with syntactic movement, or sentences with syntactic embedding, is characteristic of a syntactic impairments. However, individuals with a syntactic impairment do not usually make role-reversal errors with simple sentences that do not involve movement or embedding. This kind of errors may indicate that AL’s deficit is not in the syntactic component, but in a component involving the conceptualization of events and event roles regardless of sentence structure, or due to his difficulty in understanding the words in the sentence. Furthermore, in other tasks, AL voluntarily repeated (correctly) whole subject and object relative clauses the experimenter produced, even though he was not directed to do so. This is unusual for people with a syntactic impairment, who tend to avoid producing relative clauses, and make errors when repeating them. In the naming to a definition task mentioned above, when he was presented with the definition “A vegetable that rabbits eat”, before answering (his answer was “eggplant” and “meat”), he repeated the definition that includes an object relative clause. He also repeated the definition “an animal that has wool” (which in Hebrew includes a type of an indirect object relative clause, *xaya še-yeš l-a cemer*). Role-reversal errors even with simple sentences, and voluntarily repeating correctly sentences with object movement is non-characteristic of deficits in syntactic movement or structure building. We suggest that AL’s difficulty in syntactic tasks is secondary to his impairment in the conceptual system. Recall that in the proposed model, the conceptual system is responsible for the conceptualization of the number and type of event roles, and for the representation of the entities that participate in the event. This in turn activates the relevant argument structure (MOON) in the syntactic lexicon. In comprehension, the MOON activates the conceptual representation. If the conceptual system is impaired, It is expected that conceptual roles will not be assigned to the correct arguments in the sentence in all types of sentence, even though the grammatical components responsible to thematic role assignment are intact. This is expected not only in sentences with object movement, unlike the case of syntactic impairments, but to all types of sentences.

The semantic lexicon

CN is a 61-year-old woman with primary progressive aphasia. We concluded that CN has an impairment in the semantic lexicon on the basis of her performance in the following tests:

(1) In a picture naming task, CN was able to name correctly only 29% of the pictures. She made semantic substitutions (e.g., vase → bottle), had long hesitations, and used definitions (sock → you put it under your shoes). Phonological cues did not facilitate correct naming.
(2) A word-picture matching task was used to test whether comprehension is also impaired. CN was correct only in 55% of all items; most of her errors were “don’t know” responses, and some of them were semantic substitutions (pepper → onion). Difficulty in both naming and word comprehension points to impairment in the semantic lexicon.
(3) Word-comprehension was also impaired in reading, evident by errors in written-word association task (80% correct). This shows that her word comprehension deficit is a-modal, consistent with a deficit in the semantic lexicon.
(4) She showed intact auditory (100%) and orthographic (97%) lexical decision, indicating that her phonological and orthographic input lexicons are intact.
(5) CN performed near ceiling in a picture-picture association task, with only one error (97% correct). This indicates that her conceptual system is intact, and that her impairment is limited to the semantic lexicon and therefore restricted to language.

The syntactic lexicon

SN, RT, AO, HY were tested and diagnosed in Biran and Friedmann (2012), where data and discussion can be found.

The phonological output lexicon

The two patients, RR and HH are diagnosed and described in detail in Stark (2020). HH is a 73 year-old man who was treated in a hospital following hemorrhagic stroke in the basal ganglia of the left hemisphere.

(1) HH’s impairment in accessing phonological representations through the semantic lexicon is evident by his performance in a picture naming task (SHEMESH, Biran & Friedmann, 2004) in which he was able to name only 67% of the pictures on the first attempt, and showed a frequency effect (i.e., higher frequency of words was positively correlated with correct naming, $r = .22$, $p = .015$). He made phonological errors such as *kfafot* (‘gloves’) → *kafot* and *xagora* (‘belt’) → *kagora*, as well as semantic errors and errors of retrieving the target in a language different than the target Hebrew (English) or providing a definition.
(2) Since HH did not have surface errors in reading aloud (TILTAN, Friedmann & Gvion, 2003), which do occur in patients with a deficit in the phonological lexicon (Gvion & Friedmann, 2016), it was concluded that the representations themselves in the phonological lexicon are intact. His morphological representations in the phonological output lexicon are also intact, as he did not make morphological errors in reading.
(3) A Deficit in the phonological output buffer was ruled out because his word span were within the norm for his age, and because he showed no length effect in naming, and good performance in a spoonerism task (Gvion & Friedmann, 2003), which requires holding and manipulating representations in the phonological output buffer (10/10 in final response, 3 vowel transpositions in first attempt which were self-corrected immediately). He did show difficulty with non-word repetition in BLIP (Friedmann, 2003) (48% correct) and CILKIYOT (Friedmann et al., 2006) (74% correct), however, most of his errors were of a specific type, involving consonant substitutions, and mainly substitution of strident consonants. This error pattern can be explained by an additional deficit selectively affecting strident consonants. His poor performance in nonword repetition could also be partly explained by his hearing deficit.

RR is a 37 year-old man who was treated in a hospital following ischemic stroke in the M1 segment of MCA. RR was diagnosed with a deficit in the phonological output lexicon that affects both his access to the stems and his access to the STARs.

(1) RR had difficulty in a naming task (SHEMESH, Biran & Friedmann, 2003), 78% correct naming with a frequency effect ($r = .02$, $p = .04$). Errors were semantic, associative errors and avoidence through the use of definitions, reflecting his difficulty in accessing roots in the phonological output lexicon, as well as some morphological errors suggesting that there is a deficit in the STARs.
(2) This deficit includes a deficit to the STARs as can be seen in his performance in retrieval tasks with morphologically complex words. In a naming task for morphologically complex words (Stark et al., 2018), he had 61% correct responses, and 27% of his errors were substitution of morphological pattern. In the a word derivation task (Stark et al., 2018) in which participants are asked to retrieve nouns based on verbs and vice-versa, he also had poor performance (67% correct) crucially, with 48% of his errors being pattern substitutions. Note that these tasks did not include alternating verbs, and most of the target words were nouns.

The phonological output buffer

Some of the patients with a deficit in the phonological output buffer had additional impairments, but nevertheless, all of them showed the same pattern in verb retrieval. Here we will establish only that these patients had a deficit in the phonological output buffer.

The task we used to diagnose in impairment in the phonological output buffer was a non-word repetition task (Friedmann, 2003). Patients who performed below controls in this task and did not have an additional impairment that can explain their difficulty (a hearing impairment or a phoneme-to-phoneme conversion impairment) were included in the phonological output buffer impairment group. Since a deficit in the phonological output buffer affects reading as well, we show that all patients in this group also had a significant number of errors in a non-word reading task (Table 12 in the main text). This suggests that indeed these participants had a deficit in the phonological output buffer, and the deficit could not be (solely) ascribed to a deficit in the phonological input buffer.

Sixteen participants in this study (including participants with thiamine deficiency presented in Appendix E) were diagnosed with an impaired phonological output buffer. HY was excluded from the group analysis because she had an impairment in the syntactic lexicon, which also affects the production of alternating verbs as we showed.

Appendix E: Participants with impairment in the phonological output buffer due to thiamine deficiency

We present six additional participants who had early acquired aphasia due to thiamine deficiency during infancy, their details are presented in Table E1. These participants were diagnosed with a deficit in the phonological output buffer due to impaired nonword repetition and/or reading, presented in Table E2.

Table E1. Demographic information of participants with language impairment due to thiamine deficiency during infancy.

Initials	Age	Sex	Education
GM	16	M	In highschool
RN	15	M	In highschool
IC	16	M	In highschool
AM	15	M	In highschool
RM	16	F	In highschool
AD	17	F	In highschool

Table E2. Performance (%correct) in nonword repetition and reading that led to the diagnosis of an impairment in the phonological output buffer.

Participant	Nonword repetition (48 items)	Nonword reading (40 items)
GM	89%	83%
RN	69%	33%
IC	71%	66%
AM	88%	93%
RM	88%	54%
AD	38%	88%
Controls	$N = 20$, $M = 95.5\%$, SD = 3.5%	$N = 1073$, $M = 94.2\%$, SD = 7.2%

Shaded cells indicate significantly higher error rate compared to controls.

Participants with a deficit in the phonological output buffer due to thiamine deficiency showed the same characteristic pattern of morphological errors just like older patients with aphasia (Table 13): they had morphological errors in both derivation and inflection (this was significant for all participants except for RN), as presented in Table E3.

Table E3. Different error types for participants with a phonological output buffer deficit (% of total verbs produced).

	Derivation		Inflection	
Participant	Alternant substitution	Pattern substitution	Tense error	Agreement error
GM	2%	5%	5%	0%
RN	12%	2%	2%	0%
IC	5%	2%	2%	2%
AM	5%	5%	0%	2%
RM	5%	2%	5%	0%
AD	11%	8%	17%	2%
Controls[a] (age 10;5–11;4) $N = 18$	$M = 1.8\%$ SD = 2.7%	$M = 0\%$ SD = 0%	$M = 0.5\%$ SD = 1.4%	$M = 0\%$ SD = 0%
Controls (age 20–29) $N = 21$	$M = 1\%$, SD = 1.6%	$M = 0.2\%$ SD = 0.6%	$M = 0.6\%$ SD = 1.2%	$M = 0.2\%$ SD = 0.6%

Shaded cells indicate significantly higher error rate compared to the control group; When the relevant control group performed at ceiling, and no statistical comparison was possible, one error of a certain type was considered significant.

Even though these participants had a different clinical etiology and age compared to the patients in Table 13, they showed the same functional impairment, which caused the same pattern of morphological errors.

[a]The young control group was tested with a version of the task altered for children, with slightly different stimuli and a different number of items. Comparing the participants to the older control group, tested with exactly the same task as the patients, does not change the significance status of the characteristic error pattern.

Appendix F: The proposed model and distributed morphology

The proposed model and distributed morphology

From a linguistic point of view, we find that the model has many similarities to current theories of the architectures of grammar (even though they are typically developed as theories of representation and not of processing), and especially to Distributed Morphology (DM: Halle & Marantz, 1993), although there are some important differences. (For integration of DM into psychological models of production see Pfau, 2009. For arguments against lexicalism in psycholinguistics see Krauska & Lau, 2023). DM has two main assumptions: *late insertion* and *syntax-all-the-way-down* (Bobaljik, 2017; Harley & Noyer, 2003). *Late insertion* is the idea that the atoms of syntax do not include phonological content, which is only inserted or realized at a later stage. The idea that there are several lists or lexicons that store information of different type is not new to cognitive neuropsychology: the semantic lexicon stores abstract representations of lexical items, and the phonological lexicon stores corresponding phonological material. Naturally, since the original idea was developed in cognitive neuropsychology in the context of lexical retrieval of single words, it did not usually involve syntax. However, when attempting to generalize the retrieval of single words to alternating verbs in a sentence, we placed the syntactic component between the semantic (and syntactic) lexicon and the phonological lexicon, and allowed for one-to-many and many-to-one correspondences between lexicons. The result is similar to late insertion. *Syntax-all-the-way-down* is the idea that syntax operates below the word-level, and, as Marantz (2005) puts it, it is the only "generative engine" – the same component responsible for the derivation of sentences is also responsible for the derivation of (morphologically complex) words. Lexicalist approaches, to which DM opposes, assume that there are word derivations that are carried out in a specialized component in the lexicon. Our model differs from distributed morphology in that it does not assume that all morphologically complex words are derived by syntactic mechanisms, but rather by lexical (the syntactic lexicon, the phonological lexicon) and post-lexical components (the phonological buffer) components. We show that individuals with an impairment in these components make morphological errors (regardless of whether or not they also have a syntactic impairment). On the other hand, we do not claim that syntax does not have a role in these derivations. It is consistent with our model that alongside the lexical derivation, there is a unique syntactic derivation for different verb types (e.g., causative verbs have a different syntactic structure, or a different syntactic relation to their arguments, than non-causative verbs), and future research may recast our model in DM terms. Although we do not assume syntax-all-the-way-down, we do not think that our model is "lexicalist" either. Lexicalist theories are often criticized for assuming a second "generative engine" in addition to syntax: the "active" or "word-formation" component in the lexicon, and the fact that syntactic approaches assume only one "generative engine" is viewed as a theoretical advantage (Marantz, 2005). In this sense, our model is not lexicalist, since it does not assume any generative tools for word formation. The only role of the lexical and post-lexical components in our model is to map between different modes of representation in various components – a role that these components must play anyway to explain the retrieval of any word.