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Lexical retrieval and its breakdown in aphasia and developmental language impairment

Naama Friedmann, Michal Biran, and Dror Dotan

1. Introduction

One of the central processes in language is lexical retrieval, the process of getting from a concept to a spoken word. This process became one of the central targets for researchers of biolinguistics, and specifically, for brain research. As we will survey below, lexical retrieval is a multi-staged process, with distinct components. The main challenge of biolinguists in this area is the identification of these components, of their localization in specific brain areas, and the description of the flow of information between them over the course of time. This is done mainly via the exploration of various types of anomia, lexical retrieval impairments after brain damage, and using various brain imaging techniques.

Psycholinguists and biolinguists seek to explain the process that allows speakers to retrieve words rapidly and accurately. In fluent speech, words are retrieved in a rate of 1-3 words per second, from lexicons that include tens of thousands of words, and still, normal speakers make as few as one error in a thousand words or even less (Butterworth, 1989, 1992; Levelt, 1989). Models of lexical retrieval, developed by a group of neuropsychologists of language and cognitive psycholinguists (e.g., John Morton, John Marshall, Merrill Garrett, David Howard, Brian Butterworth, Gary Dell, Willem Levelt, Ardi Roelofs, Max Coltheart, and Lyndsey Nickels), describe the intact word production process and the possible loci of deficits in the model that cause word retrieval difficulties (see Figure 1).

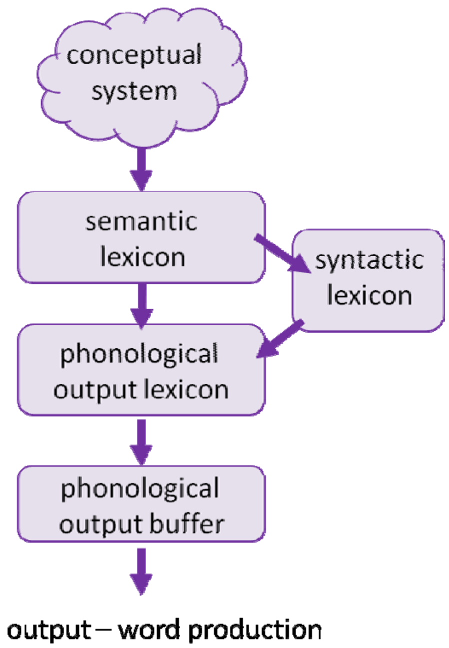

Figure 1. Stages in lexical retrieval

2. Stages of lexical retrieval

These models suggest that the first stage of the lexical retrieval process is the formation of a conceptual representation in the *conceptual system*, a representation that is still not formulated in words. This representation includes what the person knows about a concept, probably including its visual image, its semantic properties, its function etc. Such concept can be created from an idea someone has, or after identifying a visual image, such as a picture of an object or the object itself. Many cognitive psychologists and linguists (Collins & Quillian, 1969; Rips & Medin, 2005; Rosch, 1975, 1978; Rosch et al., 1976; Rosch & Mervis, 1975; Smith & Medin 1981, to name just a few), as well as philosophers (such as Gottlob Frege, Bertrand Russell, Ludwig Wittgenstein and many others), explored the questions of the nature and representation of concepts, and this question is still under research and debate.

This non-lexical concept then activates a lexical-semantic representation in the *semantic lexicon*. The semantic lexicon is organized semantically and contains words and information about the meaning of words, for example, about the semantic category, function, color, and size of the items the words refer to. According to some conceptualisations, it is actually a "hub" between the conceptual system and the lexical systems, without a content of itself. This lexicon is where semantic priming, the effect of the presentation of a word on the later presentation of a semantically related word, takes place. Semantic priming has a complex pattern – for example, whereas hearing or reading a word facilitates the access to a semantically related word that appears shortly afterwards, studies of word production found that in naming tasks it takes longer to produce a word if a semantically related word was produced shortly beforehand (Howard et al., 2006; Wheeldon and Monsell, 1994). The semantic lexicon is organized also by imageability, with high-imageability (concrete) words being easier to access than low-imageability (abstract) words (Howard and Gatehouse, 2006; Nickels, 1995; Nickels and Howard, 1994).

The selected semantic representation activates the lexical-phonological representation in the *phonological output lexicon*: the representation of the spoken form of the word, which includes the metrical information of the word (number of syllables and stress pattern) and its segmental information (its phonemes – consonants and vowels, and their relative positions, Butterworth, 1992; Levelt, 1992). A possible reason for the phonological output lexicon to keep the words broken into metric and segmental information, rather than as already-assembled words, is that words may have different phonological forms in different contexts. For example, the words "want" and "to” together do not sound like the juxtaposition of the two separate words, but are rather pronounced “wanna”; The same goes for "come" and "on”, that are pronounced together as “commun”, for "gotta" and many more. The fact that the phonological form of the word is constructed each time we use it makes it easier for the speech production system to be productive and to generate the word in many different ways, depending on the context (Levelt, 1992). The exact extent of metric and segmental information in the phonological output lexicon is still debated – for example, whether the metric information includes prosody (Butterworth, 1992), or whether there are different representations for vowels and consonants (Caramazza et al., 2000).

The phonological output lexicon is organized by word frequency, and hence frequent words are accessed more readily than less frequent ones. As for the representation of morphologically complex words (at least those with regular inflections), it seems that this lexicon only includes the stems of the word, namely, it includes "kangaroo" but not "kangaroos", "walk" but not "walked".

Lexical phonology is represented in two separate phonological lexicons: an output lexicon, which is used during speech, and an input lexicon, which is used when hearing words. The phonological output lexicon is also separate from the orthographic lexicon (Coltheart, 2004) – we may know how a word sounds, but not how it is spelled. (For example, the reader probably said the word *tomorrow* quite often, but may still wonder whether there are 2 *m*'s or 2 *r*'s in the written word; other readers may know the legal word that sound like /suh-pee-nuh/, but not know how it is spelled.) Conversely, we may know the written form of words that we often read, namely, they may appear in our orthographic lexicon, without knowing exactly how they are pronounced (this could apply to foreign names in books, such as *Yossarian*, names of lexical retrieval researchers, such as *Levelt* or *McCullough*, or city names in signs, such as *Valladolid, Llanrwst*, or *Wooloomooloo*, and to irregular words in a foreign language, such as the words *suffice*, *whole*, or *yacht* in English, when read by non-native speakers).

The activation is in turn transferred from the phonological output lexicon to the *phonological output buffer*, a post-lexical, sub-lexical stage that has two functions: maintaining activation and composition. The information that arrives from the phonological output lexicon needs to be held active somewhere until the word is uttered in full. The phonological output buffer is a phonological short-term store, which holds the phonological representation that arrives from the phonological lexicon until the word is produced (e.g., Butterworth, 1989, 1992; Dell, 1986, 1988; Garrett, 1976, 1992; Kempen and Huijbers, 1983; Levelt, 1989, 1992; Nickels, 1997; Patterson and Shewell, 1987). It holds units of various sizes: phonemes, morphemes, and number words (Dotan and Friedmann, 2007, 2010).

In its other function, the output buffer is a composer. It composes the word by inserting the phonemes into the metrical frame (e.g., Biran and Friedmann, 2005; Meyer, 1992; Shattuck-Hufnagel, 1992). It is also responsible for composing larger phonological units: it composes morphologically complex words from their morphemes (Dotan and Friedmann, 2007, 2010; Kohn and Melvold, 2000). The buffer is responsible not only for composition at the word level. It seems that the buffer (and/or the phonetic stages immediately following it) is also responsible for the phonological effects of the combination of words, such as the combination of "*want to*" into "*wanna*" that we have mentioned earlier, and possibly also for the effects of co-articulation, namely, the obscuration of the boundaries between units in speech production (Kent and Minifie, 1977). It might even be, and this is still to be tested and confirmed, that processes at the sentence level that linguists ascribe to the phonological component, the PF, such as verb movement according to some analyses (Chomsky, 1995b, 2001), occur in this stage. The output buffer is a component that is separate from the phonological input buffer (Monsell, 1997; Franklin, Buerk, and Howard, 2002; Nickels, Howard, and Best, 1997; Gvion and Friedmann, 2008, 2012a; Shallice, Rumiati, and Zadini, 2000; Shallice and Warrington, 1977). Given that the phonological output buffer is a short term memory component, it is also affected by the length of the phonemic string it holds (namely, the number of phonemes in a word, or the number of words in a multi-digit number) – longer strings that include more units are harder to maintain and produce, and strings that include more units than its capacity are impossible to maintain and produce in full.

Importantly, the phonological output buffer is involved not only in the process of word retrieval, which we have discussed so far, but also in the production of nonwords. When one reads a word that is not stored in her orthographic and phonological lexicons, be it a new word or a nonword, she would not be able to use the lexical route. In this case, she will be forced to fall back on a sublexical route of reading, which converts graphemes to their corresponding phonemes (see Figure 2 in the next section). The phonological output buffer holds the products of this conversion until production, and composes the phonemes into a string. Similarly, when one repeats a nonword (or a new or unknown word), it is the phonological output buffer that receives the phoneme string (from the phonological input buffer), holds it, re-composes it and sends it to production.

Eventually, the phonological output buffer sends the phonological representation of the word to *phonetic encoding*, the stage that prepares the phoneme string for articulation and sends it to the motor system. The phonetic encoding stage handles phonemes, and it also uses a mental syllabary, a store of pre-assembled syllables, ready for articulation. For this reason, more frequently used phonemes and syllables are activated more easily (Laganaro, 2008; Levelt, Roelofs, & Meyer, 1999). Although the mental store of syllables is located at a phonetic stage, the syllable frequency also affects the phonological output buffer (Laganaro, 2008).

2.1 The syntactic lexicon

Another component that the semantic lexicon activates, as shown in Figure 1, is the *syntactic lexicon*, which stores syntactic information about words. This lexical-syntactic information includes various aspects of words that dictate the syntactic environment in which a word can be inserted. One type of lexical-syntactic information is the information about the argument structure of the verb – the number of arguments it takes, their thematic roles (its thematic grid), and the syntactic types of the verb's complements (its subcategorization frame). For example, for the verb "kiss", the syntactic lexicon includes the information that it takes two arguments, an agent and a theme, and that the complement of the verb is a noun phrase (*The girl kissed the boy*). For the verb "think", the complement can be either a sentence (*think that the autumn is a beautiful season*) or a prepositional phrase (*think about the rain*). Namely, the lexical-syntactic information of the verb *think* includes the information that it has two different options for complementation.

Information about nouns is also encoded in the syntactic lexicon. For example, it includes information about the grammatical gender of nouns, a lexical property that determines in many languages the inflection of various constituents in the sentence that agree with the noun (Biran and Friedmann, 2012; Costa, Sebastian-Galles, Miozzo, and Caramazza, 1999; Friedmann and Biran, 2003; Schriefers, 1993; Vigliocco and Franck, 1999). It also includes information about whether a noun is count or mass (Fieder, Nickels, and Biedermann, 2011; Herbert and Best, 2010; Semenza, Mondini, and Cappelletti, 1997).

The syntactic lexicon includes (only) idiosyncratic properties of lexical items, that is, it only includes properties that do not stem from general principles of Universal Grammar or of a specific language (Chomsky, 1995b). For example, the fact that verbs in certain languages are followed by their complements (*I ate pomegranates* and not *I pomegranates ate*) is a general property of those languages (head-first languages) and therefore not part of the lexical knowledge about each verb. In contrast, the set of complements of a particular verb is an idiosyncratic property of that verb, hence part of the verb’s lexical entry. Similarly, the grammatical gender of a particular noun is an idiosyncratic property and therefore has to be listed in its lexical entry.

Response-time studies revealed that upon access to a lexical entry of a verb, all its complementation options are activated (Shapiro et al., 1987, 1989, 1991, 1993; Shapiro and Levine, 1990). Shapiro and his colleagues found that access to the argument structure of verbs is exhaustive, i.e., a verb is always activated together with all the alternative argument structures it has, and hence, accessing verbs with more argument structure options entails longer reaction times to a secondary task. Namely, it takes longer to access and retrieve a verb like "want", which can appear with several possible complements, and hence be part of several verb-phrase structures: *want an apple, want to sleep, want that the winter will finally come*, than to access a verb like "fix", which has only one possible argument structure, with a noun phrase complement (*fix the radio*). These results are further supported by imaging studies. Shetreet et al. (2007, 2010) found brain areas that are more active when a person hears a sentence with a verb that has more complementation options (subcategorization options). Thus, an effect of the number of complementation options on the access to verbs is indicative of a well-functioning syntactic lexicon. A similar pattern of exhaustive access is also reported in the noun domain – the access to ambiguous nouns (such as *letter*, for example) is also exhaustive. When we hear a sentence with an ambiguous word, immediately after the ambiguous word, all of the meanings of that word are activated. According to a line of studies by Dave Swinney and his colleagues, exhaustive access to nouns occurs even when the context strongly points to only one of the meanings (see, for example, Swinney, 1979; see also Love and Swinney, 1996; Onifer and Swinney, 1981).

A short note about the terminology in the lexical retrieval literature is in order here. In early models of lexical retrieval, researchers referred to the lexical entry in the semantic lexicon as *lemma* and to the lexical entry in the phonological lexicon as *lexeme*. With time and development of theories of lexical retrieval, different researchers used the term *lemma* in different ways. Some refer to *lemma* as the entry in a syntactic lexicon (Bock and Levelt, 1994; Levelt et al., 1998; Roelofs, 1992), others refer to it as an entry in the semantic lexicon, yet others use the term for both (Kempen and Hoenkamp, 1987; Kempen and Huijbers, 1983; Levelt, 1989, 1992), namely, according to them the lemma includes a word's semantic representation as well as its syntactic representation. Clearly, the usage of the term relates to the theory one holds with respect to whether or not there exists a syntactic lexicon that is separate from the semantic lexicon. To avoid confusion, we will not use the term "lemma" here, but rather use the, admittedly longer term, "semantic lexicon entry" and "syntactic lexicon entry".

2.2 Temporary word retrieval failures in normal speakers

Even though lexical retrieval of healthy speakers is usually efficient and rapid, this process sometimes fails. The two main ways in which it fails are cases in which the speaker tries, unsuccessfully, to retrieve a word, and cases in which the speaker retrieves an incorrect word. The temporary inability to retrieve a word is termed "*tip of the tongue*" (TOT) (Biedermann et al., 2008; Brown, 1991; Brown and McNeil, 1966; Levelt et al., 1991; Schriefers, Meyer, and Levelt, 1990). A person who tries to retrieve the word but gets stuck in a TOT state usually has full semantic information about the word she tries to retrieve, but only partial phonological information. We are pretty sure that each of the readers has experienced these states, and the feeling that the word is "on the tip of the tongue". In fact, Brown and McNeil (1966, p. 326), who were the first to systematically explore TOTs, stated that the signs of TOT are unmistakable, and depicted a person in this situation as being in "mild torment, something like the brink of a sneeze".

Many studies, starting with the work of Brown and McNeil (1966), inquired into the characteristics of this state. Research provided various characteristics of TOT. For example: people experience TOT universally, TOT states occur about once or twice a week on the average for younger adults, and their frequency increases with age. Speakers often have a feeling of knowing about the target word, and can often provide semantic and phonological information about the target words and judge whether a word is the one they are looking for or not. In about half of the TOT states, the target words are retrieved during the TOT experience, within a minute or two. TOT states frequently occur when trying to retrieve proper names. With respect to the partial phonological information, a bowed serial position effect is often noticed, as speakers in a TOT state are often able to access some of the segments of the target word, usually its first letter, and sometimes also its suffixes. They also tend to be able to recall the number of syllables in the word and the stress position, and often produce words related to the target.

The other way in which retrieval can fail in healthy speakers is in *slips of the tongue*, namely, when an incorrect word or nonword is produced instead of the target word (Fromkin, 1971; Garrett, 1976; Levelt et al., 1991; Schriefers, Meyer, and Levelt, 1990). Examination of these speech errors revealed that there are different types of errors, which can be broadly categorized into semantic errors (such as *"he sent a fax, ah.. an email"*) and phonological errors (*"choung... young children"*, or *"deand end"* instead of *"dead end"*). TOT states and slips of the tongue provide further support for the separation between semantic and phonological levels in lexical retrieval.

2.3 Naming of written words

Reading aloud of a written word is often termed "naming of a written word". Whereas this is a somewhat confusing term, because we tend to think of naming as a process that starts from a concept, looking at the model for single word reading (Figure 2) immediately clarifies in what way reading is intimately related to naming. Firstly, the output of reading aloud uses the same two phonological components we have described in detail in the previous section: the phonological output lexicon and the phonological output buffer. These components play a role not only in the production of a word from a concept but also in the production of a word that has arrived from the orthographic input lexicon. In addition, the conceptual and semantic components we have described before also take part in the reading process – they are responsible for the comprehension of written words that arrived in the orthographic input lexicon.

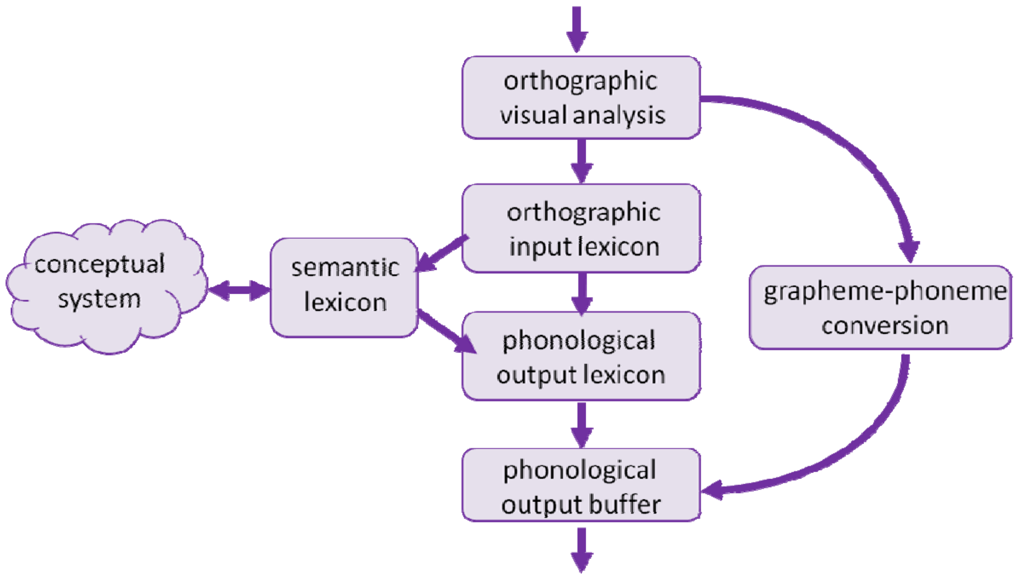

Figure 2. The dual route model for single word reading

Figure 2 shows the dual route model for single word reading. This model is the result of a work of cognitive neuropsychologists such as Max Coltheart, John Marshall, Tim Shallice, Karalyn Patterson, Andrew Ellis, Andrew Young, and others. This model describes the stages that a reader passes from seeing a written word until its "naming", i.e., reading aloud using the phonological output lexicon and the phonological output buffer. It also describes the stages of written word comprehension, via the semantic lexicon and the conceptual system. The first stage of this model includes orthographic-visual analysis that is responsible for the encoding of letter identities and position (Coltheart, 1981; Ellis, 1993; Ellis, Flude, and Young, 1987; Ellis and Young, 1996; Humphreys, Evett, and Quinlan, 1990; Peressotti and

Grainger, 1995). After this orthographic-visual analysis, the information flows in two routes for reading aloud: the lexical route, which includes the orthographic input lexicon and the phonological output lexicon and buffer, and the sublexical route, in which reading proceeds via grapheme-to-phoneme conversion. The orthographic input lexicon holds the orthographic information about the way the written words we know are written, and is connected to the phonological output lexicon. The direct connection between these lexicons allows for a rapid and accurate conversion from a written word to its phonological form. All words that the reader knows can be read via this lexical route, and it is the only route that enables the accurate reading of irregular words like *talk, knight*, or *debt*, which are stored in the two lexicons. The other route for reading aloud is the sublexical route, in which letter strings are converted into sounds via grapheme-to-phoneme conversion. This route enables the reading aloud of new words, which are not yet stored in the orthographic input lexicon, and of nonwords. In addition to these lexical and sublexical routes for reading aloud, the model includes a connection between the orthographic input lexicon and the conceptual-semantic system (through the semantic lexicon to the conceptual system), which allows for the comprehension of written words. Thus, naming of a written word shares components with the oral naming of word that originate in a concept.

3. Types of anomia

Anomia is a deficit in lexical retrieval (from *a* = not, *nomn* = name). The process of lexical retrieval can fail due to several different deficits: in the conceptual level, in the semantic lexicon, in the syntactic lexicon, in the phonological output lexicon, in the phonological output buffer, or in the connections between these components. Impairments in these different loci create lexical retrieval problems with different characteristics. Knowing these characteristics can help in identifying the exact locus of the deficit of an individual with anomia. It therefore has not only theoretical but also clinical importance, because different types of anomia often require different kinds of treatment (Nickels, 2002). Picture naming is the most commonly used task for the examination of lexical abilities (Best, 2005; Kambanaros, 2008, 2010; Levelt et al., 1998), as it involves all stages of word production and enables to examine the information the participants have about the target word, both quantitatively and qualitatively.

In the following pages we describe the various types of anomia resulting from deficits in the different possible loci. We describe the characteristics of selective anomias – namely, what happens when an individual has a single deficit along the lexical retrieval process. On top of these, there exist more complex impairments, of individuals who have a combination of deficits in several components, resulting in the combination of the relevant symptoms.

3.1 A deficit in the conceptual system

A deficit in the conceptual system is not a lexical retrieval deficit *per se*. Indeed, it results in lexical retrieval failure, but it is located in a general cognitive stage, before the lexical stages, and it is bound to cause not only difficulties in lexical retrieval but also impaired comprehension of words and sentences, presented auditorily or written, and impaired comprehension of non-verbal situations and of pictures and objects. Such individuals, who have word production disorders that result from a conceptual deficit, produce paraphasias (naming errors) that are not necessarily related to the target word, such as "bridge" for "grapefruit". They do not typically make phonological errors, and should not have any specific problems in nonword tasks such as nonword repetition (providing they understand the task), because nonword production does not involve the conceptual system. They fail not only in verbal tasks but also in conceptual tasks such as odd-one-out in pictures (for example, a picture of a pen, pencil, eraser, and a tooth brush), and picture association test (asking, for example, which of two pictures is more closely related to a picture of an umbrella – a picture of the sun or a picture of a rainy cloud). Such a conceptual impairment is typical for at least some of the aphasics who are diagnosed with Wernicke's aphasia.

3.2 A deficit in the semantic lexicon, semantic anomia

A deficit in the semantic lexicon would also cause incorrect naming, but would take a different form. Individuals with semantic anomia mainly produce semantic paraphasias, such as *table* for *chair*, *giraffe* for *zebra*, or *apple* for *plum*. They might show an imageability effect, with better production of high-imageability (concrete) words than of low-imageability (abstract) words, and prototypicality effect, with more typical items of the category, like *apple*, being produced instead of the less typical ones, like *plum* (Cohen-Shalev and Friedmann, 2011). Because the semantic lexicon is most probably shared by production and comprehension processes, individuals with impairment at the semantic lexicon fail not only in word retrieval but also in the comprehension of written and heard words. Unlike individuals with a conceptually-based deficit, the deficit of individuals with an impairment to the semantic lexicon is limited to the verbal system. They perform well in picture tasks such as picture odd-one-out and picture association, but fail in the parallel tasks that involve words. Thus, they show difficulties in written and spoken word versions of the odd-one-out and word association tasks (asking, for example, to choose a word that is more closely related to the written/heard word "umbrella", between the two written or heard words “sun” and “rain"). Because semantic anomia is rooted in a lexicon, and not in the phonological buffers, individuals with this type of anomia read and repeat nonwords correctly, and do not make phonological paraphasias in naming.

A further phenomenon that is ascribed to a deficit in the semantic lexicon is category-specific naming impairment. Individuals with this deficit may be impaired, for example, in retrieving the names of living things but not of nonliving things, or show a reverse pattern, with greater difficulty with nonliving things than living things (e.g., Capitani et al., 2003; Humphreys and Forde, 2001; Laiacona et al., 2001; Mahon and Caramazza, 2006; Tyler and Moss, 2001; Warrington and McCarthy, 1983, 1987; Warrington and Shallice, 1984). The deficit applies not only to word retrieval but also to input tasks such as providing attributes pertaining to heard names of animals. The grain of specificity of the category specific impairment can be quite striking. For example, patients have been described who have a deficit in living animate things (i.e., animals) but not in living inanimate things (i.e., fruit/vegetables, Caramazza and Shelton, 1998; Damasio et al., 1990; Silveri and Gainotti, 1988). Other patients show a selective deficit in fruits and vegetables. As an explanation for these category-specific semantic impairments, Caramazza and Shelton (1998) suggested that the semantic-conceptual system is organized domain-specifically, according to an innate sets of categories.

3.3 A deficit in the phonological output lexicon – lexical-phonological anomia

A deficit in the phonological output lexicon also causes incorrect naming, but this naming disorder exhibits different characteristics than the two previously described deficits. Individuals who are impaired in this level understand concepts well, and can access their corresponding representation in the semantic lexicon, but fail to activate the correct entry in the phonological output lexicon. As a result, they make phonological paraphasias. Typically, these individuals make not only phonological paraphasias but also semantic paraphasias, possibly because they do not have access to the phonological representation of the target word and thus a representation of a semantically-related word is activated (see Caramazza and Hillis, 1990, and Howard and Gatehouse, 2006).

Because the phonological output lexicon is organized by frequency, these individuals show a frequency effect (Jescheniak and Levelt 1994)., whereby they make more errors on the least frequent target words (in fact, the phonological output lexicon is the only module in the speech production system that is sensitive to word frequency, and causes such a frequency effect). Because this deficit is in a stage following the conceptual and lexical-semantic stages and does not affect them, individuals with a deficit in the phonological lexicon perform well on conceptual comprehension tasks with pictures. Because their deficit is in the phonological output lexicon, which is separate from the phonological input lexicon, they understand heard (and written) words well. Because nonword production does not involve the lexicons, they do not have problems in reading or repeating nonwords.

Another implication of a deficit in the phonological output lexicon relates to reading aloud. Recall that the phonological output lexicon is part of the lexical reading route (Figure 2), the route that allows for accurate and rapid reading, and is especially crucial for reading aloud of irregular words. When the phonological output lexicon is impaired, reading aloud, even of words, cannot proceed via the direct lexical route, and reading must therefore be done via the sublexical route (see Gvion and Friedmann, 2012c for a report of individuals with acquired and developmental anomia in the phonological output lexicon who demonstrated surface dyslexia in reading aloud). Reading through the sublexical route results in words being read more slowly, and irregular words being read aloud incorrectly (for example, *walk* may be read with a pronounced *l*). The incorrect reading is most evident in reading potentiophones, words that when read via the sublexical route can be read as another existing words. These potentiophones can be read as the other word – for example, *know* can be read as *now*, and *angle* as *angel*. Thus, a deficit in the phonological output lexicon results not only in phonological and semantic errors in naming but also in regularization errors in reading aloud, which are characteristic of surface dyslexia (Broom and Doctor 1995; Castles, Bates, and Coltheart, 2006; Castles and Coltheart, 1993, 1996; Coltheart and Byng, 1989; Coltheart and Funnell, 1987; Coltheart, Masterson, Byng, Prior, and Riddoch, 1983; Ellis et al., 2000; Ferreres et al., 2005; Friedmann and Lukov, 2008; Howard and Franklin, 1987; Judica, de Luca, Spinelli, and Zoccolotti, 2002; Marshall and Newcombe, 1973; Masterson, 2000; Newcombe and Marshall, 1981, 1984, 1985; Temple, 1997; Weekes and Coltheart, 1996).

Semantic errors occur both in a semantic lexicon impairment and in a phonological lexicon impairment, however, there are several straightforward ways to distinguish between these impairments. Firstly, word comprehension is impaired in a semantic-lexicon impairment but not in a phonological output lexicon impairment. Secondly, phonological output lexicon impairment also entails phonological errors, whereas individuals with semantic lexicon impairment do not make phonological errors. Finally, deficits at the semantic and phonological lexicons are affected by different types of cues and treatments. As Nickels (2002) indicated, for each type of naming deficit, resulting from a deficit in different stages of processing, a different type of treatment will be suitable. Thus, a treatment that focuses on word meaning (e.g., picture-word matching task) would help in cases of semantic naming deficit, and a treatment that focuses on the phonemes of the word (e.g., word repetition task) would be effective in cases of phonological naming deficit (see also Makin, McDonald, Nickels, Taylor, and Moses, 2004, and Nickels, 2002). Indeed, phonological treatments (using repetition, rhyming, or first phoneme) were found to improve word retrieval for phonologically impaired patients in several studies (Lambon Ralph, Sage, and Roberts, 2000; McDonald et al., 2006; Miceli et al., 1996; Raymer, Thompson, Jackobs, and Le Grand, 1993). An improvement due to a semantic treatment was reported by Hillis (1998), who described a patient with a semantic impairment (as well as impairments in other levels of processing) whose naming was improved after a treatment that focused on "teaching specific semantic features".

This difference between semantic and phonological facilitation was also found for cues. Namely, when, upon retrieval failure the experimenter provides the patient with a cue, either phonological or semantic. Biran and Friedmann (2002) reported that individuals with impairment at the lexical-semantic level were assisted by a semantic cue and individuals who were impaired at the phonological level were assisted by phonological cues.

3.4 A deficit in the connection between the semantic and the phonological output lexicons

Impaired naming can result not only from a deficit in the components themselves, but also from disconnections between them (as Carl Wernicke has noticed already in his 1874 book). The impaired connection that is most easily described and distinguished from a deficit in the components is the impaired connection from the semantic lexicon to the phonological output lexicon. This disconnection results, like lexical-phonological anomia, in phonological and semantic paraphasias, alongside good comprehension of pictures and words, and good reading and repetition of nonwords (and this was in fact the pattern presented by the classic case of patient Johann Voit, described by Garshey and discussed by Wernicke, 1886, see De Bleser's, 1989 translation of Wernicke's paper, and Bartles and Wallesch, 1996 for a discussion). It differs from lexical-semantic anomia in that individuals with this disconnection are expected to understand heard and read words well, but to fail in producing them. It differs from lexical-phonological anomia in that reading can still be done via the phonological output lexicon, and hence the reading should not include regularizations of irregular words.

3.5 A deficit in the phonological output buffer – phonological buffer anomia

Individuals with phonological output buffer impairment also have word production problems. Their error pattern includes only phonological errors, and no semantic errors (they may, when failing to produce a word, produce instead another word that is similar in meaning, but they would know that it is not exactly the word they meant to use). Because their deficit lies a long way after the conceptual and semantic stages, they have no problems in comprehension tasks of pictures, written words, or auditorily-presented words. They do have a marked difficulty with nonwords, because the phonological output buffer is responsible for holding and composing phonemes of nonwords, in reading and repetition tasks. Their difficulty with nonwords and new words is often more severe than their difficulty with real words, because nonwords cannot rely on activations from the lexicon to support their production.

Because the phonological output buffer is a phonological short term component, it is affected by the length of the phonemic string it holds – strings that are longer than its capacity are affected (Franklin, Buerk and Howard 2002; Nickels 1997), and their phonemes are omitted or substituted. Therefore, a word *length effect* indicates the involvement of the buffer, and naming in phonological output buffer anomia is considerably influenced by the length of the target word (unlike deficits in earlier stages). Additional effects that are unique to anomia in the phonological output buffer, or in the phonetic encoding stage, are the syllable and phoneme frequency effects: individuals with phonological output buffer anomia make fewer errors in frequent syllables than in infrequent syllables, and fewer errors in frequent phonemes than in less frequent ones (Goldrick and Rapp, 2007; Laganaro, 2005). Syllable and phoneme frequency are inter-correlated, and Laganaro (2005) found that the analysis of frequency by syllables is more reliable. The syllable frequency effect is assumed to be caused by failure of access to the mental store of syllables, which holds pre-assembled syllables (Laganaro, 2008). The phonological output buffer is closely related to phonological short term memory (pSTM). When tested in pSTM tasks, individuals with impaired phonological output buffer typically show poor recall performance in tasks such as digit span, word span, and nonword span (Gvion and Friedmann, 2012a,b). In pSTM tasks that involve recognition, without oral recall, these participants may show normal performance, unless their phonological input buffer is also impaired.

Finally, recall that the phonological output buffer composes words from phonemes and metrical information, and morphologically complex words from morphemes. Therefore, a deficit in the phonological output buffer affects these composition procedures. Importantly, because the buffer handles units of different sizes (phonemes, pre-assembled morphemes, and pre-assembled whole digit names), a deficit in this buffer has different effect on these different types of words. Words are produced with incorrect order of phonemes (fennel → fellen) or with substitution or omissions of phonemes (fennel → feddel); morphologically complex words are produced with substitution, omission, or addition of morphemes (adjustment → adjustive); and numbers are produced with digit substitutions (4068 → four thousand sixty three). Crucially, because the morphemes and the digits are already pre-assembled in the buffer, individuals with phonological output buffer anomia usually do not make phonological errors within morphemes or within digits. Individuals with (output) conduction aphasia are typically impaired in the phonological output buffer (Franklin, Buerk, and Howard, 2002; Gvion and Friedmann, 2012a; Pate, Saffran, and Martin, 1987; Shallice, Rumiati, and Zadini, 2000).

3.6 A deficit in the syntactic lexicon

Deficits in the syntactic lexicon are somewhat different in nature than the aforementioned anomias. Whereas it is a deficit in the process of lexical retrieval, it typically does not cause errors in the traditional single word tasks of picture naming. Such deficits do have far-reaching implications, especially for sentence construction. If we take grammatical gender as an example for information in the syntactic lexicon, in many languages when requested to name a picture of an object, a bare noun suffices, and there is no need to access the gender of the noun. However, when this noun is incorporated in a sentence or a phrase, in many languages this would require the agreement of another constituent (such as the article) with this noun, or in syntactic terms, this would include an agreement feature that needs to be checked. In this case, the gender of the noun in the syntactic lexicon needs to be accessed. If the syntactic lexicon is impaired, the agreement of the noun with the verb, with pronouns, adjectives, and determiners would fail. Therefore, to detect an impairment in the syntactic lexicon, tasks at the phrase or sentence level should be used (Biran and Friedmann, in press; Friedmann and Biran, 2003; Schriefers, 1993).

Impairments at the syntactic lexicon can also selectively affect the speaker's knowledge of the complements and arguments the verb can appear with (its *predicate argument structure*, *subcategorization*, *thematic grid*, or *complementation frame*). If this information is impaired, this can also critically hamper the construction of sentences. Sentences can be produced without the required complements, or with incorrect complements. Such impairment in the Predicate Argument Structure has been termed "aPASia" (Biran and Friedmann, 2012). In a study that used the effect of the number of complementation options on reaction time, Shapiro and Levine (1990) and Shapiro et al. (1993) found that individuals with Broca's aphasia showed the effect, and hence demonstrated sensitivity to verbs' PAS. In contrast, individuals with Wernicke's aphasia did not show sensitivity to the number of complementation options that a verb has in its lexical entry. This suggests that an impairment in Wernicke's area (left STG) causes aPASia.

Whereas this impairment in the syntactic lexicon clearly affects the syntactic structure of sentences, it should not be confused with another condition, agrammatic aphasia, which affects the syntactic structure building, but does not necessarily affect the syntactic knowledge at the single word level (Shapiro and Levine, 1990; Biran and Friedmann, 2012). Similarly, in developmental language impairments, children may have significant syntactic deficits without a deficit to the syntactic lexicon (Kenan et al., 2007).

3.7 A summary of the properties of the various types of anomia

This pattern of impairments suggests a way to diagnose the locus of impairment of each person with a naming impairment. In Figure 3 we summarize the main error types and effects distinguishing between the different impairment patterns.

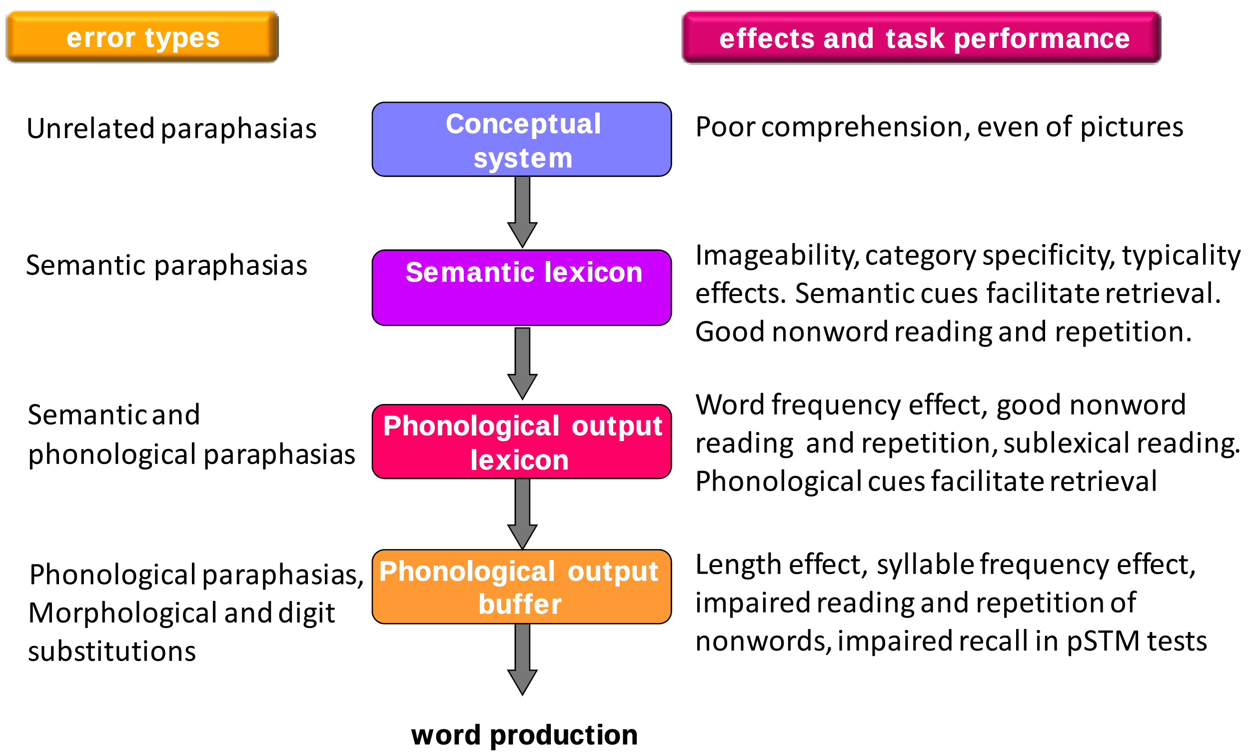

Figure 3. Errors and effects that characterize each of the types of anomia

4. Developmental anomia and its subtypes

Naming deficits are frequent among children with impaired language. For example, Dockrell et al. (1998) reported that 23% of the children treated by speech therapists in the UK had naming deficits. When a child has a lexical retrieval deficit, it manifests itself in naming tasks as well as in free conversation (German, 2002).

Several studies examined the types of errors children produce when they fail to retrieve a word and the types of preserved information they have. These studies found that children produce various types of errors: semantic errors, phonological errors, "don't know" responses, unrelated errors, and visual errors (Dockrell et al., 1998; Kambanaros and Grohmann, 2010; Lahey and Edwards, 1999; McGregor, 1994, 1997, and others). Semantic errors seem to be the most frequent type of naming error in both language-impaired and typically developing English-speaking children aged 3-6 (McGregor, 1997), but language-impaired children produced more phonological errors than the typically developing children. McGregor et al. (2002) also found that semantic errors were the most frequent, and that most of them were coordinate (i.e., at the same level of object – *car-train*), in a group of typically developing children aged 5-7 years.

Moreover, there is evidence supporting the separation between processing of semantic and phonological information in children, like in adults after brain damage. Faust, Dimitrovsky, and Davidi (1997), for example, found that Hebrew-speaking language-impaired children in second and third grades could provide semantic information regarding words they could not retrieve phonologically. Namely, they had access to the semantic information of the word but not to its phonological information, indicating separate semantic and phonological levels.

Importantly, it seems that developmental lexical retrieval deficits take very similar forms to the ones revealed in the work on acquired lexical retrieval deficits in adults. Some researchers take the view that it is possible to apply the framework developed in the research of adults with acquired anomia to developmental disorders, of course considering the developmental stage of the child (Best, 2005; Friedmann and Novogrodsky, 2008; Novogrodsky, Kreiser, and Friedmann, 2010). Firstly, within this view, developmental language impairments cause selective impairment in various language abilities. Thus, developmental language impairments include selective deficits in syntax (syntactic SLI or SySLI, Friedmann and Novogrodsky, 2008, 2011), with good lexical retrieval abilities, and impaired lexical retrieval (a deficit that received various names, including lexical SLI, LeSLI, developmental anomia, and dysnomia), with unimpaired syntax. Then, within the developmental lexical retrieval deficit, distinct types can be identified, in line with the types described above for adults with acquired anomia.

To demonstrate how children and adolescents with lexical retrieval impairments may be classified into the different anomia patterns described above, we bring here four case studies, whose loci of impairment are summarized in Figure 4. Esther, Michal, and Ofer are Hebrew-speaking children described in Friedmann, Hadar-Ovadya, and Levy (in press), and Revital was described by Novogrodsky, Kreiser, and Friedmann (2010).

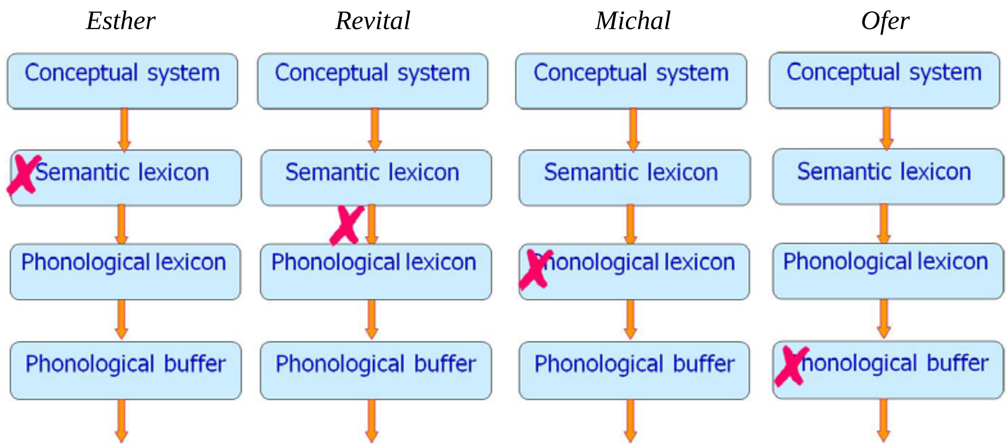

Figure 4. The loci of impairment of four children with developmental anomia

4.1 Esther, a girl with developmental semantic lexicon anomia

When we met Esther and evaluated her lexical retrieval abilities, she was in 4th grade and 10;2 years old. She named correctly only 81% of the words in a picture naming test (on which age-matched typically-developing children perform 95% correct and above). Esther performed well in the association tests that involved pictures, and had no semantically unrelated paraphasias, which indicates that her conceptual system was intact. She had many semantic paraphasias, and poor performance in the association test in which the items were words rather than pictures. She demonstrated a category-specific deficit in fruits and vegetables, and semantic cues helped her word production. All these symptoms are consistent with a semantic lexicon deficit. She had no phonological paraphasias, and phonological cues did not help her production, indicating that her phonological output lexicon was intact. She also showed no length effect, and good nonword repetition and reading, indicating that her phonological output buffer was intact.

4.2 Revital, a girl with developmental anomia in the connection between the semantic and phonological lexicons

When we met Revital she was in 6th grade and 12;9 years old. She named correctly only 74% of the words in the picture naming test. Like Esther, she performed well in the picture matching conceptual tests, and had no semantically unrelated paraphasias, which indicates that her conceptual system was intact. Her impaired picture naming included 28% semantic errors and 8% phonological errors, showing that her deficit could not be ascribed to a pure deficit at the semantic lexicon: had she had a semantic lexicon deficit, one would not expect phonological errors. She also did not have a deficit in the phonological output buffer: her repetition of nonwords and her reading of nonwords were intact. She also showed normal phonological STM. Another indication for the involvement of the phonological stages (and specifically the phonological lexicon, because an impairment in the phonological output buffer was ruled out), on top of her phonological errors in naming, was the fact that phonological cues helped her retrieve words.

To distinguish between a deficit in the phonological output lexicon itself and a deficit in the access to this lexicon from the semantic lexicon, we assessed her oral reading of irregular words and potentiophones. Her very good reading of irregular words indicated that she is able to read via the lexical reading route (the route between the orthographic input lexicon and the phonological output lexicon), and hence her deficit is not in the phonological output lexicon. Thus, all these symptoms are consistent with a deficit in the access from the semantic lexicon to the phonological output lexicon, and this was indeed our diagnosis.

4.3 Michal, a girl with developmental phonological lexicon anomia

Michal was a 10;2 year old girl in 4th grade when we tested her lexical retrieval abilities. She named correctly only 81% of the words in the picture naming test. She performed well in the association test that involved pictures, and had no unrelated paraphasias, indicating that her conceptual system was intact. She also performed well in the lexical association task, indicating an intact semantic lexicon. In the naming task she produced semantic and phonological paraphasias. She showed word frequency effect, and her reading was characterized by surface dyslexia. All these suggest that her phonological output lexicon was impaired. Her phonological output buffer, conversely, was intact: she showed no length effect, good repetition of nonwords, good reading of nonwords, and good performance in the phonological STM recall tasks.

4.4 Ofer, a boy with developmental phonological output buffer anomia

Ofer was a 11;3 year old boy in 5th grade when we tested him. He named correctly only 84% of the words in a picture naming test. Like the three other participants, he performed well in the association test that involved pictures, and had no unrelated paraphasias, indicating an intact conceptual system. In addition, he had good performance on the association test that included written words, and in word-picture matching tasks, indicating that his semantic lexicon was intact.

He produced mainly phonological paraphasias, and made only few semantic paraphasias, which he immediately corrected. Phonological cues of first phoneme helped him retrieve all but one word he had been unable to retrieve before the cue. All these findings point in the direction of a deficit at the phonological output stages.

The picture with respect to effects on his naming and the production of nonwords provides the last piece of the puzzle, by answering the question of whether his deficit is at the phonological output lexicon or a deficit at the phonological output buffer. Ofer showed no frequency effect on his naming, but did show length effect and syllable frequency effect. He demonstrated poor repetition of nonwords, poor reading of nonwords, and poor phonological working memory, all indicating an impairment in the phonological output buffer.

5. The biology of lexical retrieval development

Thus, it is clear that developmental anomia exists, and in fact, various types of developmental anomia exist. Not much is known at this stage about the biological basis of these selective impairments, or about the biological path of the development of lexical retrieval. Some studies focus on the genetic bases of language impairments, as summarized in the chapter by Benítez-Burraco. One recent study pointed at another cause for developmental lexical retrieval impairments. Fattal, Friedmann, and Fattal-Valevski (2011) conducted a study of children who suffered a deficiency in one specific micronutrient, thiamine (vitamin B1), during their first year of life. Their lexical retrieval was tested when they were 5-7 years old. Thiamine plays a central role in cerebral metabolism. It serves as a cofactor for several enzymes involved primarily in carbohydrate catabolism, converting glucose to energy, the only energy source in the brain. These enzymes are important in the biosynthesis of a number of cell constituents including neurotransmitters. Thiamine also has a structural role in membrane structure and function, it intervenes in synaptic transmission, and plays a role in cellular differentiation, synapse formation, axonal growth, and myelinogenesis.

Fattal et al.'s study tested the effect of thiamine deficiency on lexical retrieval. They discovered that 88% of these children showed significant lexical retrieval impairments. They had hesitations, "don't know" responses, semantic paraphasias, and some morphological errors. The conceptual abilities of these children were generally intact, their IQ was normal, and their vocabulary was normal. The thiamine deficiency during infancy thus seems to have caused long-lasting disorders in lexical retrieval, in the establishment of the cascaded mechanism for lexical retrieval we described in this chapter. Because of the general role thiamine plays in the brain and in brain development, it is probable that the effect of thiamine deficiency is not on a specific brain region that specializes in lexical processing. One possible mechanism is that when the brain is unable to provide the necessary substrate for the development of the lexical retrieval mechanism during a certain critical period, the damage is permanent. This mechanism cannot develop at a later stage, after the critical period, even if thiamine is already present. This study thus demonstrates that thiamine is crucial for the development of the normal process of lexical retrieval, and it also suggests that the development of this process has a certain early critical period. (See Calderon and Naidu, 1998; Yoshinaga-Itano, 2003; Yoshinaga-Itano and Apuzzo, 1998a, 1998b for studies that report results regarding early critical period for language and communication abilities in general, and see Friedmann and Szterman, 2006; Szterman and Friedmann, 2003, for critical period for first language syntax. See also Ruben, 1997 for different critical periods for different language domains, and Monjauze et al., 2005 for a discussion of critical period in children with epilepsy.)

6. Lexical retrieval in the brain

There are several methods to map the functional components of lexical retrieval onto specific brain locations. One group of methods assesses brain activations in the healthy brain; the other assesses brain areas in individuals with anomia. Within the realm of imaging of normal brains, one method is using brain imaging results to compare brain activations during different tasks, and looking for brain regions that show specific activation patterns (Indefrey, 2007, 2011; Indefrey and Levelt, 2000, 2004). For example, brain regions that serve the semantic lexicon or the phonological output lexicon are expected to be active in tasks of picture naming but not during nonword production. Another method, aiming to identify brain regions that are *necessary* for word production, is looking for regions in which transient lesions, induced by electric stimulation, interfere with certain word production tasks (Indefrey, 2007, 2011, and references therein). Yet another method is using MEG to break down the time course of naming and identify different parts of sequential naming processes

(Indefrey and Levelt, 2004; Levelt et al., 1998).

Finally, a way that is more intimately related to the types of anomia we have discussed above is targeted at identifying brain areas that are necessary for the various components of lexical retrieval. This is done using structural imaging of the brains of individuals with anomia, by looking for shared brain areas that are impaired for a group of individuals with an impairment in the same functional component.

6.1 Brain areas identified in imaging studies with healthy speakers

Indefrey and Levelt (2000, 2004) and Indefrey (2011) conducted comprehensive meta-analyses of tens of imaging studies of the regional cerebral brain activation patterns observed during various lexical retrieval tasks.

Conceptual processing was found, in imaging studies as well as in aphasia research, to involve widespread activation in a large set of brain regions, including the posterior inferior parietal lobe, middle temporal gyrus (MTG), the fusiform and parahippocampal gyri, the dorsomedial prefrontal cortex, the inferior frontal gyrus (IFG), ventromedial prefrontal cortex, and posterior cingulate gyrus, primarily in the language dominant (usually left) hemisphere (Binder et al., 2009; Binder and Price, 2006).

The next stage in lexical retrieval is the access to the entry in the semantic lexicon. Indefrey et al.'s meta-analyses indicated that the mid section of the left MTG is active during word generation and picture naming, but not during reading. They concluded that this region serves the “conceptually-driven lexical selection” (Indefrey, 2011), which, within the model we presented above, can be thought of as the activation of the semantic or the syntactic lexicon from the conceptual system. This mapping is also supported by the fact that semantic priming effects were also found in this region (de Zubicaray et al., 2001), and lesions in this region were found to be associated with semantic errors in aphasic patients (Schwartz et al., 2009). Data from MEG studies show a relatively large range of activation times, but it is still largely compatible with the assumption that the left MTG is activated around an early time window of 175-250 milliseconds, the time window during which the selection of the entry in the semantic lexicon is assumed to occur (e.g., Maess et al., 2002). An MEG study conducted by Levelt et al. (1998) reported activation related to the semantic/syntactic lexicon in the right parietal cortex, along the posterior end of the superior temporal sulcus.

Not many studies investigated the neural representation of the syntactic lexicon. However, a series of fMRI studies of the representation of argument structure by Shetreet et al. (2007, 2009a, 2009b, 2010; Shetreet & Friedmann, 2012) pointed to several areas that are repeatedly activated with respect to lexical-syntactic properties of verbs. These areas include the left posterior superior temporal gyrus (STG), the MTG, the precuneus, and two areas in the IFG, which do not include Broca's area: BA 9 and BA 47.

The phonological output lexicon was identified in some imaging tasks by being involved in the production of words but not of nonwords. This pattern is most evident in the posterior parts of the left superior and middle temporal gyri (namely, the information seems to flow posteriorily and superiorily from the area identified as the semantic lexicon). Another type of evidence for the involvement of the left STG in lexical-phonological activities can also be seen in the reduced activation in this area when a phonological distractor is used (Bles and Jansma, 2008; de Zubicaray et al., 2002). Analysis of effects showed it to be sensitive to lexical frequency but not to word length and object familiarity – a pattern that is consistent with the phonological output lexicon (Graves et al., 2007; Wilson et al., 2009). Finally, MEG studies on the left STG show activation times largely consistent with the time window starting at 275 milliseconds after the presentation of the stimulus and onwards, which is assumed to be the time in which the phonological output lexicon is accessed (see Indefrey, 2011 and references therein). Levelt et al. (1998), in a pioneering MEG study of lexical retrieval, ascribed phonological encoding to the posterior STG and the temporoparietal junction. It should be noted, however, that not all researchers share this view regarding the phonological output lexicon activations in posterior STG. Edwards et al. (2010), for example, claim that the left posterior STG participates only in speech comprehension, and its role is speech production is merely auditory self-monitoring.

With respect to the localization of the phonological output buffer, it seems that studies of lesions of individuals with conduction aphasia, which we review below in Section 6.2, provide a fuller picture than the imaging studies with healthy participants. Hickok and Poeppel (2007) suggest that the phonological buffer is represented in area Spt (Sylvian parietal temporal – an area within the Sylvian fissure at the parietal-temporal boundary), which activates Broca's area and sends it motor rather than phonological information. According to Hickok and Poeppel, the phonological buffer is an emergent property of sensory-motor circuits and sensory-motor integration (see also Buxbaum et al., 2011).

In search for post-lexical areas, Indefrey (2011) mentions the left posterior IFG in relation to the the syllabification process, and presents in detail the controversy about the exact role of this area, and in which post-lexical process it is involved. Data from individuals with an impairment in the phonological output buffer, which we survey below, suggest that the left posterior IFG serves later, post-lexical stages, rather than the phonological output buffer. The right supplementary motor area (SMA) and the left anterior insula were also mentioned as post-buffer phonetic areas, related to articulatory processing (Indefrey, 2011; Indefrey and Levelt, 2004).

6.2 Brain areas identified from lesions of individuals with anomia

DeLeon et al. (2007) used a different approach to associate brain areas with specific cognitive functions. They examined a group of 116 aphasic patients who were within 24 hours from an acute left hemisphere stroke. They assessed these patients' functional impairment in lexical retrieval and matched it to their brain lesions. First, they administered to each patient a battery of language tasks, and identified the functional locus of impairment for each patient. They did this by analyzing error types, similarly to the analyses described throughout this chapter. This resulted in classifying the patients into four groups, according to their functional deficit: (1) a deficit in the conceptual/semantic system; (2) a deficit in a lexical stage that is common to speech and writing, which they termed "modality-independent lexical access"; (3) a deficit in the phonological output lexicon; and (4) a deficit in post-lexical stages, i.e., the phonological output buffer or the articulatory stages. Along this functional classification, DeLeon et al. analyzed brain imaging data (obtained using magnetic resonance diffusion and perfusion imaging) to identify the anatomic areas damaged by the stroke in each patient. Eventually they performed statistical analysis to associate the brain areas with the functional deficits. Using this procedure, they discovered several areas that are crucially involved in the various stages of lexical retrieval. An important difference exists between functional imaging studies of healthy participants and studies like De Leon et al.'s, which assess brain lesions and their functional effects. Whereas functional imaging studies of healthy participants provide evidence for the areas that are reliably activated in a certain task or comparison of tasks, studies of lesions can provide a window into which areas are *necessarily* involved in a specific functional stage.

DeLeon et al.'s study found that lesions in Brodmann areas 21 (which roughly corresponds to the MTG) and 22 (STG, including Wernicke's area) were most frequent in the group of patients with a semantic/conceptual deficit. They therefore concluded that these areas serve the conceptual/semantic system – namely, the conceptual system and/or the semantic lexicon. Indeed, area 21 more or less overlaps the MTG, which, according to the imaging studies on healthy participants described above, serves conceptual processes and "semantically driven lexical access".

A deficit in modality-independent lexical access stage (which might correspond to the semantic lexicon) and in the phonological output lexicon were associated with left Brodmann 37 (posterior, inferior temporal/fusiform gyry) and 39 (angular gyrus), again, areas adjacent to (though not identical with) the left posterior STG and MTG, which were found as the areas serving the phonological lexicon in imaging studies of healthy individuals.

The post-lexical deficit was found, in DeLeon's study, to be associated with lesions in areas 44 and 45 (inferior frontal gyrus, IFG, Broca's area), but it seems that these areas were not involved in the phonological output buffer but rather in later motor and articulatory processes (as can also be seen in another study of a temporary lesion of Broca's area, Davis et al., 2008). Generally, studies of impairments in the phonological output buffer in conduction aphasia have consistently indicated that phonological buffer impairments are related to lesions in the STG and inferior parietal cortex (Baldo, Klostermann, and Dronkers, 2008), mainly in the left posterior STG (Hickok et al., 2000; Hickok and Poeppel, 2007) and in the anterior supramarginal gyrus (Palumbo et al., 1992; Damasio and Damasio, 1980). Within these two areas, the output type of conduction aphasia (and hence, phonological output buffer) is probably localized in the supramarginal area, and the superior temporal areas are more probably related to the phonological input buffer (Axer et al., 2001).

7. Epilogue

Thus, the lexical retrieval process is a complex, multi-staged process, which is tightly related to other language domains such as reading, comprehension, and syntax. We have described in this chapter the various stages of this process, their biolinguistic bases and neural correlates, and the patterns of acquired and developmental anomias that result from selective deficits in each of the stages. The ever growing body of theoretical and empirical knowledge on the normal process of lexical retrieval contributed to the study of lexical retrieval breakdown and its neural substrates. Knowing the various ways in which lexical retrieval can break down and the way the various lexical retrieval components are implemented in the brain, in turn, have provided constraints on the theory of lexical retrieval. Apart from the importance of the theoretical knowledge that has accumulated about lexical retrieval, theories and research of normal and impaired lexical retrieval, bear insurmountable importance for the diagnosis of the specific deficit of each individual with anomia, and for the selection of the most appropriate treatment for each individual.

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