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Neural Network Modeling of the Development of Phonemic Paraphasias and the difference between Phonemic Paraphasias and Paragraphias Produced by Two Individuals with Aphasia

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Abstract

Background: Although phonemic and graphemic paraphasias are a common deficit in people with aphasia, and many studies focused on the description of their occurrence, little research has been undertaken on modeling the errors with a neural network. *Aims:* Phonemic and graphemic substitution, omission, addition, and metathetic errors are modeled with a neural network in order to visualize their origin in the production process. Additionally, the developments of verbal phonemic errors over time and the difference between phonemic errors in verbal and written production are modeled. *Methods:* In this study, a total of 63 phonemic and eighteen graphemic errors, collected from test data from two patients, were analyzed and modeled with an Abstract Neural Network, that is, a simplification of the Neural Network proposed by Boersma, Seinhorst, and Benders (2012). Modeling these error types in an Abstract Neural Network, provides insight into the origin of the errors and both the quality and quantity of an aphasic's connections between the different levels of representation in the Abstract Neural Network. Data from patient 1 is used to show how damaged connections may recover over time; while data from patient 2 provides insight into the relation between verbal and written processing systems. *Results:* At test moment 1, patient 1 made more vowel substitution and addition errors than at test moment 2; however, more consonant substitutions, omissions and metathetic errors occurred at test moment 2 than at test moment 1. Patient 2 made more graphemic than phonemic errors, but specific segments were impaired in both systems. *Conclusions:*Although it was expected for patient 1 that less errors would occur at test moment 2, this turned out not to be the case, possibly due to the involvement of Executive Functions in the production process. For patient 2, it can be concluded that although verbal and written production are argued to occur via different systems and in different networks, their neural network lexicons seem to be connected to a certain extent, rather than operating entirely separately. *Future applications:* The neural network model used in this paper can be a valuable asset to aphasia diagnostics, as it will allows for the evaluation of production and comprehension routes, including the identification of specific nodes and connections involved and their possible impairments. Collecting a detailed overview of impaired elements of a person's neural network, will facilitate more specific, connection-focussed, speech therapy program.

Keywords: aphasia, phonemic paraphasias, phonemic paragraphias, neural network, language models, bi-directionality, Executive Functions

Acknowledgements

As I wrote my BA thesis on a literature-related topic, writing this thesis in linguistics has been quite a challenge. When I started working on my initial topic, Optimality Theory, I faced difficulties when trying to model the data with OT tableaux, and, eventually, decided to change my theoretical approach from OT to neural networks. With time passed, I still had to collect my data; fortunately, I was able to collect patient data from my internship at Rijndam Rehabilitation Center in Rotterdam. After narrowing my focus and research aims, I started with a preliminary table of content and wrote up my thesis chapter by chapter. While writing this thesis, I learned how to critically review sources and analyze data, to bridge theory and practice, and how to convey my initial idea and enthusiasm for this study to my supervisor, Silke Hamann.

Silke, I want to express my appreciation to you for believing in my ideas and supporting me with your expertise, inspiration, and willingness to assist me in solving problems, as well as your guidance in showing me the way when I felt lost. Your feedback and our talks have helped me a great deal, both in the process of writing as well as overseeing the bigger picture. Second, I would like to thank Jiska Wiegers, clinical linguist at Rijndam and my internship supervisor, for obtaining access to patient data and for the talks we had about my thesis, the PALPA model, and data interpretation in general. You have taught me a lot about clinical linguistics, both the theoretical and the practical side of it. Many thanks also to Nadine Bloem and Luisa Seguin for proof-reading my paper, listening to my ideas, and, most of all, being my good friends. Thanks to my family for their love and support in the preparation, writing, and, especially, finishing of this thesis. Finally, and most importantly, I would like to express my love and appreciation to my wife, who has listened to my ideas, provided feedback, and, most importantly, supported and loved me through every step of the way.

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List of abbreviations

Below a list of abbreviations used in this paper is provided.

CVA	Cerebro Vascular Accident
PALPA	*Psycholinguistic Assessment of Language Processing in Aphasia*
AAS	Auditory Analysis System
AIL	Auditory Input Lexicon0
SS	Semantic System
POL	Phonological Output Lexicon
PL	Phoneme level
VAS	Visual Analysis System
VIL	Visual Input Lexicon
GOL	Grapheme Output Lexicon
GF	Grapheme Level
UF	Underlying Form
SF	Surface Form
AudF	Auditory Form
ArtF	Articulatory Form
TB	Temporal Buffer
IPA	International Phonetic Alphabet
ACM	Arteria Cerebri Media
iCVA	ischemic Cerebro Vascular Accident
tpo	time post onset
BNT	*Boston Naming Task*
BBT	*Boston Benoem Taak*
CAT-NL	*Comprehensive Aphasia Test* – Dutch adaptation
T1	test moment 1
T2	test moment 2
C	consonant
V	vowel

List of symbols

Below a list of symbols used in this paper is provided.

“ ”	used to indicate concept from the Semantic System
| |	used to indicate Underlying Form phonemes
/ /	used to indicate Surface Form phonemes
[ ]	used to indicate Auditory Forms
<< >>	used to indicate Underlying Form graphemes
< >	used to indicate Surface Form graphemes
' '	used to indicate the concept of the word form (also called the Visual Form)

1. Introduction

Phonemic paraphasias and paragraphias are errors in language production that occur on the level of individual segments in individuals who suffer from aphasia. Phonemic paraphasias are a common phenomenon in all types of aphasia. Before the 1980's, analysis of phonemic paraphasias focused primarily on distinctive feature analysis, which included analysis of target and error segments on the level of, for example, place, manner, and voice features. A criticism on this approach was that it "ignored valuable contextual linguistic information and did not allow for the individual's active participation in phonological production" (Parsons, Lambier, & Miller, 1988, p. 46). Meaning that with distinctive feature analysis, distinctive features of the target and error items are analyzed outside of their linguistic context, not considering the possible influence of adjacent segments. A following approach of analysis included phonological process analysis, which did account for "the linguistic context of phonological errors" and regarded "the individual as engaging in a rule ordered behaviour, that is, using phonological processes" (Parsons et al., 1988, p. 46). However, although patterns may be discovered using phonological process analysis, the clinical implication on the basis of this type of analysis may still be limited, since, if "treatment is to remediate the phonological disorder, then an understanding of the underlying mechanisms causing the disorder is required to plan treatment" (Parsons et al., 1988, p. 53). Over the years, studies into phonemic paraphasias have focused on various topics, such as a comparison between normal slips and phonemic paraphasias (Wheeler & Touretsky, 1997), perceptual and acoustical analysis in fluent and non-fluent patients (Holloman & Drummond, 1991), psycholinguistic modeling of phonemic paraphasias in an attempt at accounting for neologistic jargon (Buckingham, 1987), the role of abstract phonological processes in word production (Béland, Caplan, & Nespoulous, 1990), and the relation between phonemic paraphasias and the structure of the phonological output lexicon (Michal & Friedmann, 2005). The latter research focused on the preservation of metrical and segmental information, and concluded that "metrical information and segmental information are accessed in parallel rather than serially, and are merged at a later stage in which the segments are inserted into the word form" (p. 589). Additionally, it was proposed by Ellis and Young proposed in their 'language processing model' (1988), that spoken and written production apply different cognitive systems, causing errors made during either type of production to originate from different sources.

Graphemic errors are, in essence, the written counterpart of phonemic errors. Research into graphemic errors focused on, among other things, serial order and consonant-vowel structure in the Graphemic Output Buffer Model (Glasspool & Houghton, 2005), spelling errors in different languages (for example for Spanish: Valle-Arroyo, 1990), the structure of graphemic representations (Caramazza & Miceli, 1990), graphemic jargon (Schonauer & Denes, 1994), and the

Graphemic Buffer and attentional mechanisms (Hillis & Caramazza, 1989). However, although some research has been carried out into graphemic errors, it still remains a "relatively neglected domain of investigation" by both cognitive psychologists and linguists (Caramazza & Miceli, 1990, p. 244).

To sum up, many different studies have been conducted into various topics that relate to phonemic and graphemic errors. However, little to no research has been conducted into the origin and localization of phonemic paraphasias and paragraphias, especially not with the help of a neural network model. Neural network modelling is a relatively new method of analysis, as it mostly involved digital computations. Neural network modeling research is therefore still in its early stages. In connection with aphasic symptoms, neural network modeling has focused primarily on word level processing (for example, Weems & Reggia, 2006; Järvelin, Juhola, & Laine, 2006; Laine & Martin, 2006; Hurley, Paller, Rogalski, & Mesulam, 2012). Little to no research has been done to model phonemic and graphemic errors, made by individuals with aphasia, with neural networks.

1.1 Research questions and hypotheses

In researching phonemic paraphasias and paragraphias in individuals with aphasia with the help of a Neural Network, the question is:

- How can a Neural Network account for the development of phonemic paraphasias and the difference between phonemic paraphasias and phonemic paragraphias?

The research question can be divided into two sub-questions:

- How does a Neural Network account for the development of phonemic paraphasias over time?
- How does a Neural Network account for the difference between the occurrence of phonemic paraphasias and paragraphias?

Due to the lack of studies on the current topic, hypotheses for the present research questions are not based on theoretical frameworks provided by previous studies. On the basis of the separate system idea proposed by Ellis and Young (1988) as explained above, it is hypothesized that phonemic and graphemic errors are not the same and/or related, because both types of errors originate from separate systems. It is furthermore hypothesized, that phonemic and graphemic error types occur in different parts of the Neural Network and that they originate from impairments to specific nodes and connections within the network. The final hypothesis includes the assumption that all types of phonemic paraphasias will decrease over time, as nodes and connections should improve from speech therapy.

The present paper will continue and provide an overview of aphasia as an acquired language disorder, an explanation of phonemic and graphemic errors, and an overview of the PALPA language model that serves as the basis for the theoretical framework in chapter 2. Chapter 3 will include information on neural networks in general, the specific neural network used in this paper, including its formalization. Chapter 4 is the method section, including information on patients, materials, procedures, the data overview, results, and a discussion. Finally, the final chapter will include a general conclusion as well as future and clinical implications of the present study.

2. Aphasia – a language disorder

This chapter provides an introduction to aphasia, and includes anatomical and physiological information about the condition, as well as linguistics deficits accompanying it in section 2.1. Subsequently section 2.2 provides a definition of phonemic paraphasias and paragraphias as well as an overview of the different types, and, finally, section 2.3 introduces the PALPA language model which forms the basis of the Abstract Neural Network used in this paper for the analysis of the data on phonemic paraphasias and paragraphias.

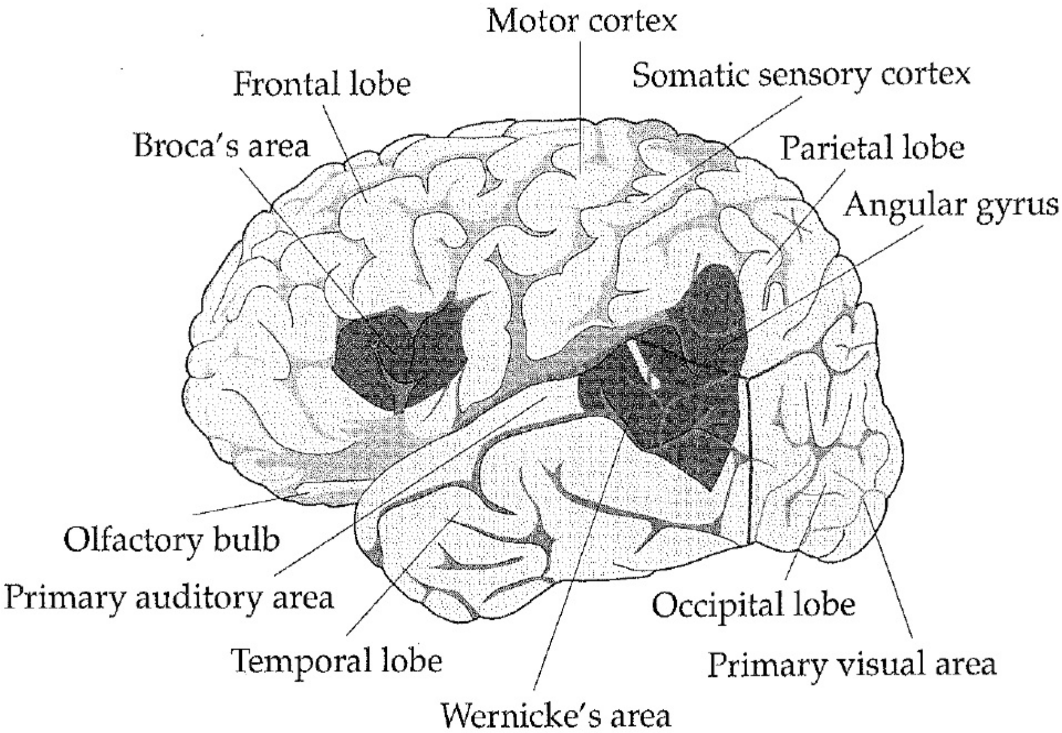
2.1 Aphasia and the brain

Aphasia is an acquired language disorder caused by sudden damage to the language processing areas in the brain after language acquisition has been completed. In most cases, brain damage results from a Cerebro Vascular Accident (CVA) (Bastiaanse, 2011), which is the medical term for a stroke during which the blood flow to a particular part of the brain is stopped by either a blockage or a rupture of a blood vessel. Other possible causes of brain damage are a trauma to the head, a brain tumor, or an infection in the brain. In approximately 95 to 98% of all right-handed people and 70% of all left-handed people language is represented in the left hemisphere of the brain (Bastiaanse, 2011). Most people with aphasia thus have a lesion in the left part of their brain. The brain is divided into two hemispheres and each consist of four lobes, namely, the frontal lobe, the temporal lobe, the occipital lobe, and the parietal lobe, see figure 2.1 below. Each lobe represents different functions in the brain (from Bastiaanse, 2011, p. 29):

- Frontal lobe: motor skills, including articulation, and language (mainly grammatical abilities);
- Temporal lobe: hearing, auditory analysis and recognition, and language (mainly word images);
- Occipital lobe: vision;
- Parietal lobe: sense and memory for time and space, praxis, and sensory skills.

The two main areas in the brain responsible for language are Broca's area and Wernicke's area, located in the frontal and temporal lobe respectively, see figure 2.1 for the location of both areas. Broca's area is located in the pars opercularis and pars triangularis of the third convolution in the frontal lobe of the left hemisphere (Caplan, 2002). This area plays an important role in the representation of grammar. Although grammar has not been located in Broca's area specifically, Broca's area and surrounding areas need to be intact in order to have normal functioning grammatical processing. When this area is damaged, a person will speak agrammatically and non-

Figure 2.1 The four lobes, including the language areas, in the left hemisphere (from Caplan, 2002, p.593)



fluently. Agrammatic speech is characterized by impoverishment and simplification of the sentence structure, resulting in the primary use of content words (nouns, verbs, and adjectives) and few instances of function words (words with a grammatical function such as demonstratives, prepositions, and personal pronouns) and grammatical morphemes (such as verb inflection and plurals of nouns).

Wernicke's area is situated in the posterior part of the superior temporal gyrus, adjoining the area of auditory analysis in the left hemisphere (DeWitt & Rauschecker, 2013). This area is the location in the brain were word forms are stored, which makes this area crucial for both language production and comprehension. Damage to this part of the brain causes word production and comprehension deficits, which could result in severe communication problems. Although speech is relatively fluent, it does contain paraphasias and/or neologisms, which, in some patients, will result in incomprehensibility. Although an impairment which includes damage to Wernicke's area mainly concerns the word-level, sentences are often paragrammatic, that is, errors are made in the application of grammatical rules.

The language deficits present in individuals with aphasia thus depend on the lesion site in the brain, combined with many personal factors, such as age, sex, education, social status, medical history, and possibly even handedness. Therefore, no two people with aphasia present with the exact same deficits. Impairments are mostly specific in that, for example, an individual may seem to have intact comprehension, but may have underlying difficulties comprehending complex sentences, such as reversible or passive sentences as in 2.1a and b respectively.

(2.1) a. The woman chased the man.
b. The police officer was painted by the ballerina.

Finally, language deficits present in an individual with aphasia may be of syntactic, semantic, and/or phonological nature. To a certain extent, all individuals with aphasia, despite lesion site or personal factors, make phonological errors in the form of phonemic or literal paraphasias. This type of language deficit is the topic of this paper and will be explained in detail in the next section.

2.2 Phonemic paraphasias and paragraphias

Phonemic, or literal, paraphasias and paragraphias are language deficits produced on phoneme or grapheme level during the effort to speak or write respectively. There are different types of phonemic paraphasias, and the labels, definitions, and divisions of which vary between sources. As, to date, there is no classification of phonemic paragraphias, the error types and definitions of phonemic paraphasias will also be employed for the paragraphias. This paper uses the error types and definitions below (from Bastiaanse, 2011, p. 35):

- substitution: replacing one or more phonemes or graphemes within a word, for example, 'putter' instead of 'butter';
- omission: exclusion of one or more phonemes or graphemes from a word, for example, 'cara' instead of 'camera', including cluster reduction, which can be defined by the reduction of phoneme clusters to singletons, for example, 'pants' instead of 'plants';
- addition: the addition of one or more phonemes or graphemes to a word, particularly to the interior of a word, for example, [bəlid] instead of 'bleed' for speech production or 'claen' instead of 'clan' for written production;
- metathesis: changing the order of phonemes or graphemes or syllables within a word, for example, 'deks' instead of 'desk'.

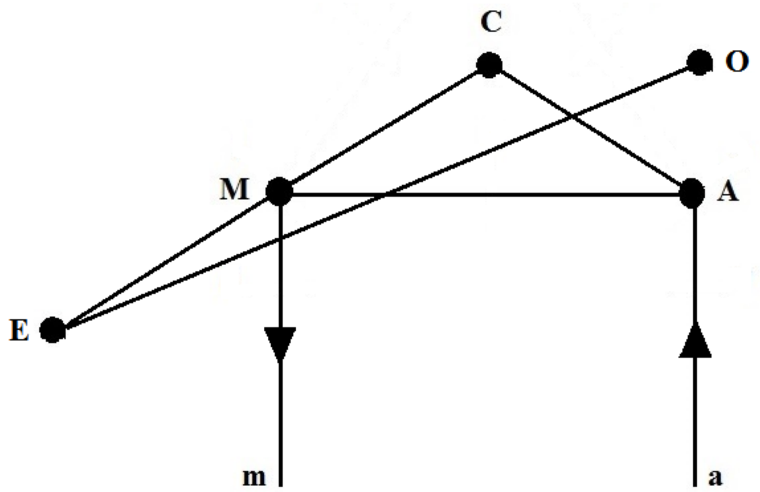
It is important to note that phonemic paraphasias and paragraphias vary both inter- and intra-individually and that according to Matthews (1997), “a single individual may produce a systematic error at one attempt at a target only to successfully produce the same target upon a subsequent trial” (p. 644). In addition, the level of self-awareness of the errors produced also varies within each individual. Consequently, individuals who are aware of their errors may apply a process called *conduite d'approche*, which is “successive approximations in an effort to achieve an accurate output” (Matthews, 1997, p. 644).

In the early 1990's scientists started to focus on researching the sound level of language processing, particularly on distinguishing phonemic paraphasias occurring with the different aphasia syndromes. In contrast to research carried out since Blumstein (1973), which focused on similarities, differences in phonemic paraphasias became the topic of investigation. Kohn (1988) was one of the first to attempt at localizing phonemic errors for different types of aphasia in the various steps of language processing. Identifying the various types of paraphasias on the basis of Kohn's system has proven not to be without complications, as localization of errors with Kohn's system mostly provided multiple options for the exact location. Finally, thus far, no classification system for graphemic errors has been proposed and little research has been done on phonemic errors in writing of people with aphasia.

2.3 Language model history

Discoveries, regarding the location of language functions in the brain, of scientists like Paul Broca (1824-1880) and Carl Wernicke (1848-1905), served as a foundation and inspiration for models of language production and comprehension processing in the brain (Laine & Martin, 2006). Following Wernicke's ideas, Ludwig Lichtheim (1845-1928), among others, was of the opinion that, with the help of a diagram, all important aphasia symptoms were explicable by presuming lesions in one or more language centers and/or the connections between them. Reversely, he also believed that, given the location of a lesion, valid predictions could be made about aphasic symptomatology resulting from that lesion (Bastiaanse, 2011). Lichtheim and others eventually developed the Lichtheim language processing diagram (1885), see figure 2.2 below. The diagram contains five cortical cognitive centers, one for verbal language production (in the diagram indicated with M = Broca's area), verbal language comprehension (A = Wernicke's area), written language production (E), written language comprehension (O), and the concept center or *Begriffszentrum* (B). The 'aA' connection indicates incoming verbal auditory stimuli, and the 'Mm' connection indicates the connection between the articulatory center and the motor center for articulation (Bastiaanse, 2011). On the basis of theoretical implications, lesions within or between different centers were associated with specific aphasia syndromes. The large focus on theories and diagrams, instead of empirical findings, caused researchers to, on the one hand, postulate aphasia syndromes which did not, or rarely, occurred, and, on the other hand, to ignore certain clinical aphasia types that did not fit the diagram. Despite the heavy criticism, the diagram does form, in a slightly altered way, the basis for the present-day aphasia classification system as proposed by Goodglass (1981).

Figure 2.2 The classical Lichtheim language processing diagram (1885; from Bastiaanse, 2011, p. 73)



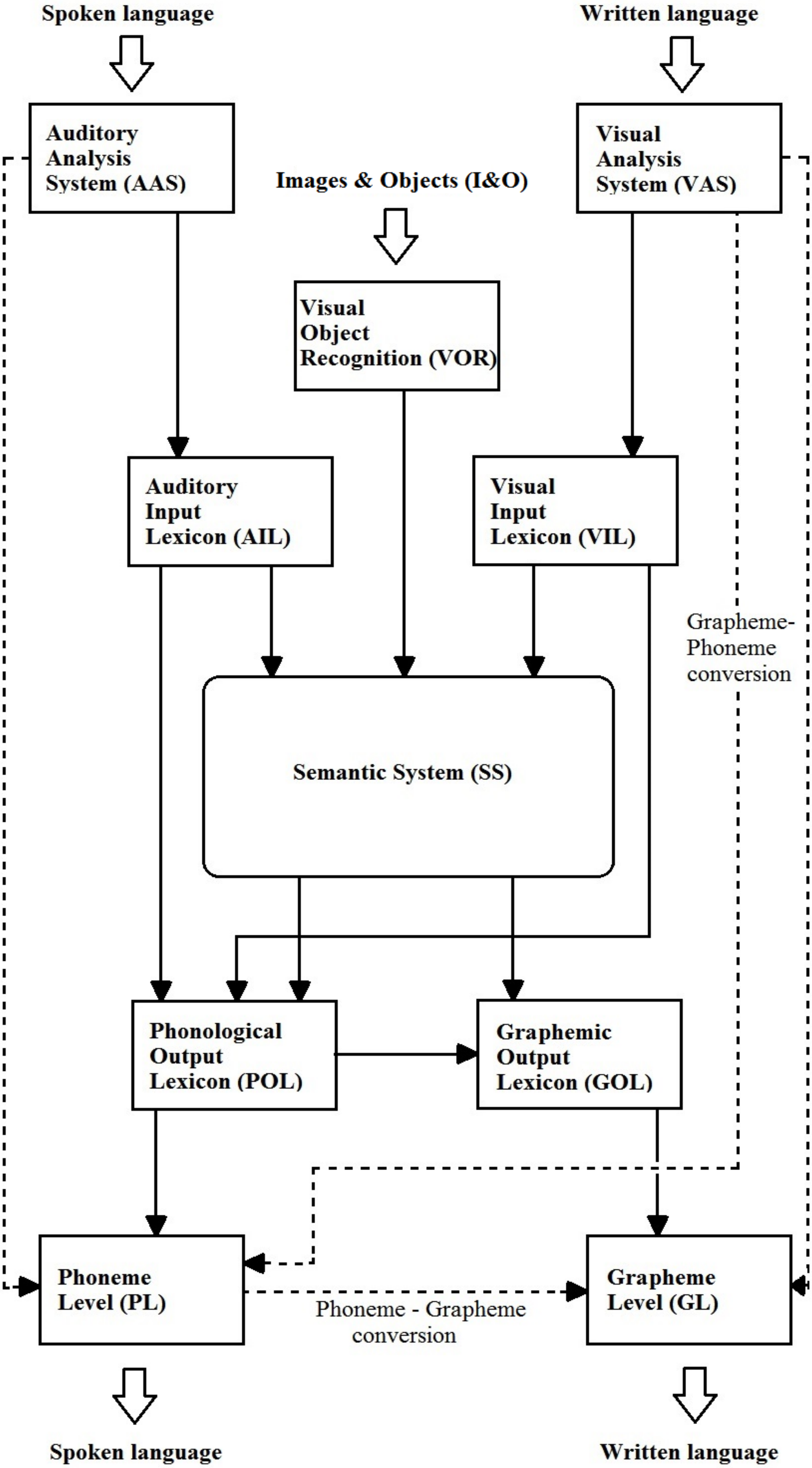
In the decades following the Lichtheim language processing diagram, the first elaborated strict localization model of language component interactions, the focus of analysis shifted a number of times, with the first linguistic approach by Roman Jakobson in the 1960's (Bastiaanse, 2011). The 1970's represent the rise of the cognitive neuropsychological approach to aphasiology in which modules and process of language processing were not related to neuroanatomical models, like scientists did in previous decades, but were rather based on production and comprehension test results of both aphasic *and* healthy speakers. The underlying thought behind this approach was twofold: on the one hand the researchers wanted to understand and model language processes in normal, healthy individuals, and on the other hand, they wanted to apply these models to analyze underlying deficits in individuals with aphasia for clinical purposes. One of the models that was based on this principle is the language processing model proposed by Ellis and Young (1988); which, in turns, formed the foundation of the language processing model that underlies the *Psycholinguistics Assessment of Language Processing in Aphasia* (PALPA) (Kay, Lesser, & Coltheart, 1992), which will be introduced and explained in the next section.

2.4 The PALPA language processing model

Errors in phonology may arise from different sources within the process of language processing. This paper uses a model of language processing which finds its origin in a language test battery called the *Psycholinguistics Assessment of Language Processing in Aphasia* (PALPA) (Kay, Lesser,

& Coltheart, 1992), which is a more detailed version of the original language processing model as

Figure 2.3 PALPA language processing model (from Kay, Lesser, & Coltheart, 1992, p. xvi)



proposed by Ellis and Young (1988). Test batteries, like the PALPA, "yield detailed profiles of spared and impaired processes" enabling clinicians to "identify the nature of the language impairment more precisely and decide what aspects of language to treat" (Laine & Martin, 2006, p. 3). The PALPA model is chosen as the theoretical background for this study, because its elaborate structure allows for an in-depth analysis of errors occurring within and between specific levels of representation. The model, presented in figure 2.3 above, furthermore encompasses both auditory and written language processing, as well as processing visual input in the form of images and objects. The elements from this model and their connections form the basis of the Abstract Neural Network designed for this study, which will be explained in more detail in the next chapter. The information provided in this section originates from the PALPA user manual (Kay, Lesser, & Coltheart, 1992) and the book *Afasie* (Bastiaanse, 2011).

Auditory processing is represented on the left-hand side of the model, and consists of:

- Auditory Analysis System (AAS): used for the analysis of sound in terms of sequence of sounds;
- Auditory Input Lexicon (AIL): includes all auditory word forms and enables recognition of auditory word forms as existing words without activating the meaning of the word. The output of this system enables the language used to activate the accompanying meaning of the word with the help of the Semantic System (SS);
- Semantic System (SS): processing of semantic information of a word, such as visual characteristics, categorical information, characteristics, function, relation with other concepts/meanings;
- Phonological Output Lexicon (POL): includes a 'database' with all words a speakers has at his/her disposal. The output of this system is an abstract word form specification;
- Phoneme Level (PL): on the basis of the activated output of the POL, the corresponding sounds are selected and put in the correct order. The output of this process is used as input for articulatory processes.

Written processing is represented on the right-hand side of the model, and consists of:

- Visual Analysis System (VAS): used for grapheme identification and analysis of successive letters. The output of this system enables the language used to look up a written word in the Visual Input Lexicon;
- Visual Input Lexicon (VIL): a collection of all written word forms a person has at his/her disposal, which enables identification of a written word as being an existing

word, without the necessity of activating the meaning;

- Semantic System (SS): this is the same SS as used for auditory processing. The first step in written (and spoken) word production is activation of all distinctive characteristics of meaning in the SS;
- Graphemic Output Lexicon (GOL): includes a 'database' with all words a speaker has at his/her disposal. If the meaning in a word is insufficiently specified, the target word cannot be selected unambiguously;
- Grapheme Level (GL): uses the output of the GOL. The correct letters are selected in the correct order on the basis of the activated word form. The output of this process is used as input for the motor processes included in writing.

2.4.1 Specific level impairment

As explained before, deficits in language processing in individuals with aphasia, may come in an abundance of variation. Moving from the focus on lesion location to the different levels of the PALPA language processing model, the deficit an individual may present with, depends on the exact location of impairment. Damage to the brain may affect a level from the language processing model exclusively or in combination with others, or even the connection(s) between levels. Below an overview can be found of the deficits that accompany damage to specific verbal levels. Note that only the verbal and written output channels are listed here; this is done because both participants from the present study have successfully completed tests for auditory, visual, and written comprehension. The information provided in the section below also originates from the PALPA user manual (Kay, Lesser, & Coltheart, 1992) and the book *Afasie* (Bastiaanse, 2011).

Below an overview is provided of the deficits accompanying the impairments to the levels of verbal word production:

- Damage to the SS – also known as 'semantic disorder' – may present with:
    - intact auditory processing, but semantic deficits cause semantic paraphasias;
    - effect of imaginability: words with a high imaginability contain less errors than those with a low imaginability.
- Damage to the Access to POL – also known as 'phonological access disorder' – may present with:
    - phonological paraphasias;
    - “it is not a ...”, is used in attempt to 'browse' the lexicon in search for the right word;

  - intact identification of target word;
  - circumlocution;
  - zero-responses;
  - effect of cues: if the first phoneme is provided, POL is accessed more easily.
- Damage to the POL – also known as 'word selection disorder' – may present with:
  - phonological-verbal paraphasias;
  - difficulties with compounds;
  - effect of frequency: less frequent words contain more errors than more frequent words.
- Damage to the PL – also known as 'word production disorder' – may present with:
  - phonological paraphasias;
  - neologisms;
  - *conduite d'approche*;
  - word length effect: longer words contain more errors than shorter words.

Damage to articulatory planning and execution, also known as verbal apraxia and dysarthria respectively, will not be discussed further in this paper.

Below an overview is provided of the deficits accompanying the impairments to the levels of written word production:

- Damage to the SS – also known as 'semantic disorder' – may present with:
  - intact written processing, but semantic deficits cause semantic paragraphias;
  - effect of imaginability.
- Damage to the Access to GOL – also known as 'deep agraphia' – may present with:
  - phonological agraphia;
  - semantic paragraphias;
  - difficulties with written word form retrieval;
  - inability to use alternative phoneme-grapheme conversion;
  - intact identification of target word;
  - effect of cues.
- Damage to the GOL – also known as 'lexical or surface-agraphia' – may present with:
  - phonemic paragraphias;
  - correct spelling of regular and non-words;

    - phoneme-grapheme-conversion can be used for spelling irregular words as they sound;
    - effect of frequency.
- Damage to the GL – also known as 'peripheral agraphia' – may present with:
    - phonemic paragraphias;
    - neologisms;
    - word length effect.

In addition to the section on damage to Access to GOL above, the phoneme-grapheme conversion can be used to spell irregular words, when the (Access to) GOL is damaged; the spelling will, however, result in a word being written as it sounds, because of the phoneme-grapheme conversion (Beeson & Rapcsak, 2004).

The identification of symptoms of production disorders in the various levels of the PALPA model, is necessary for understanding the information on the different levels of representation in a neural network in chapter 3 and the data analysis in chapter 4.

2.5 Summary

This chapter has provided an introduction to aphasia, an acquired language disorder, including its characteristics and diversity of manifestation. The information on aphasia was followed by an definition of the different types of phonemic paraphasias and paragraphias which form the theoretical foundation of the data set in the present study. Finally, the PALPA model was introduced and expounded on; the elements from this model will serve as the foundation of the neural network, which will be the subject of the next chapter.

3. Neural Networks

This chapter will contain a brief history of the origin of neural networks in section 3.1, followed by section 3.2 on the Neural Network model and the resemblance of a neural network to the neuroanatomical working of a neuron in the brain, and section 3.3 on the formalization of the Abstract Neural Network as used for analysis in this paper.

3.1 Connectionist models

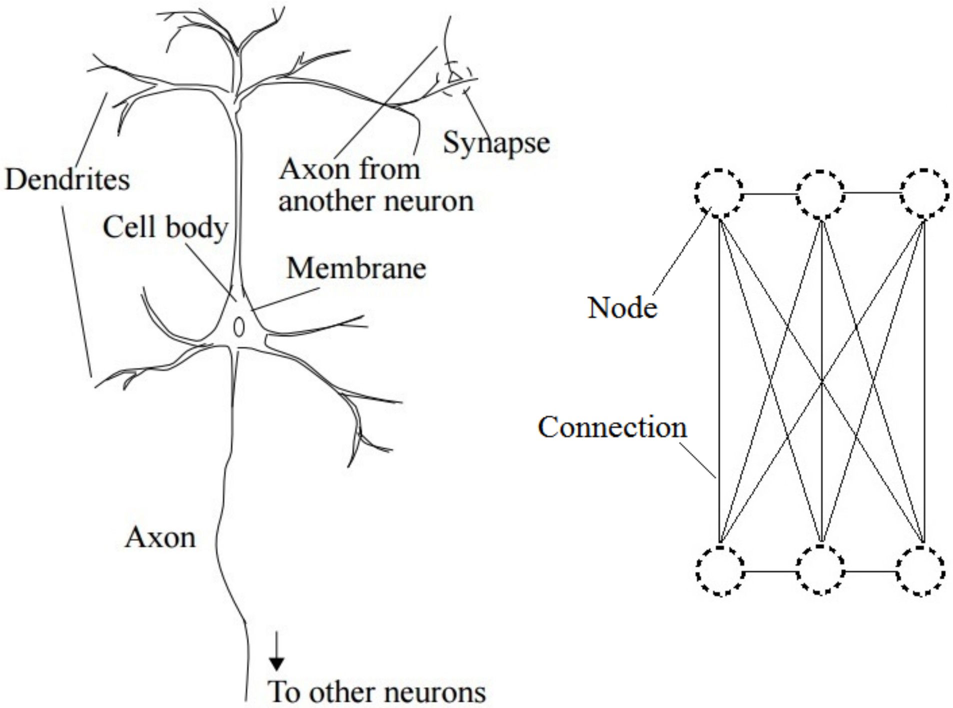
The 1980s marked the beginning of the rise of a new type of model, the so-called ‘connectionist’ models of language processing. Connectionist models describe mental processes in terms of interconnected networks and allow for speculation about the language processes involved within and between different levels of representation. This type of model also has the ability of exploring temporal and other language features in normal and impaired language use. The connectionist model differs from cognitive models, as discussed in the previous chapter, in that the cognitive approach provides a theoretical framework for understanding the mind, whereas the connectionist approach provides interconnected networks to model mental and/or behavioral processes (Bastiaanse, 2011).

One of the most often used connectionist models is that of neural networks. This paper uses Neural Networks to gain insight into the associations and dissociations between various levels of language processing. To this day, the use of a Neural Network, as proposed by Boersma, Benders, and Seinhorst (2012) as a model for analysis, interpretation, and clinical application of data from language impaired individuals is still in its early stages.

3.2 The Neural Network model

A neural network is a schematic representation of how communication works in the brain. Potagas, Kasselimis, and Evdokimidis (2013) described the neuroanatomical working of this communication in the brain in their chapter on elements of neurology related to aphasia. According to them, the brain consists of about 100 billion neural cells, which, via an axon and one or more dendrites, may “establish up to 10,000 connections with other neurons via synapses” (p. 27). These synapses uni-directionally transmit electric signals between neurons. The central nervous system allows neurons to continuously rearrange their synapses, which is the “core element of the brain's capacity for functional reorganization” (p. 27). This functional reorganization is a process called *plasticity*, which forms the basis for “rehabilitation techniques used for correcting brain dysfunctions”, like, for example, language impairments in aphasic individuals (p. 27). Figure 3.1 below shows a realistic representation of a neuron and its extensions and a neural network representation of it, on the left and right-hand side respectively.

Figure 3.1 Realistic and schematic representations of a neuron (from Negishi, 1998, p. 5)



A Neural Network, as proposed by Boersma et al. (2012), can be thought of as a network which includes different levels of representation. 'Neural Network', written with capital letters, will be used in this paper to refer specifically to the neural network as introduced by Boersma et al. (2012). In their paper, Boersma et al. (2012) explain the levels of representation in their Neural Network as consisting of “a large set of network *nodes*, each of which can be active or inactive” (p. 5). Active nodes, also called “clamped” nodes, are represented with closed circles, inactive nodes with a dashed line as in the right-hand side of figure 3.1 above. “Activity can be spread between and within levels; the knowledge of how activity has spread over time, in a learning algorithm, is stored as *connection weights*, that is, the strengths of the connections between the nodes” (p. 5). How damage to the brain may influence connection weights and the activity that spreads between nodes will be discussed and modeled in chapter 4.

3.3 Formalization of the Neural Network

In this section, the various elements of formalization of the neural network, as used for the data analysis in this paper, will be introduced and illustrated.

3.3.1 An Abstract Neural Network

Due to limitations of time, an abstract version of Boersma et al.'s (2012) Neural Network, here called Abstract Neural Network, will be used in order to model the different types of phonemic paraphasias, including substitutions, omissions, additions, and metathesis. By abstract, I mean that no algorithms or calculations will be applied to determine the acquisition of the connection weights. Instead, connection weights are described in this paper in terms of 'present' or 'absent' and as 'weaker' or 'stronger'. This is done because focus in this paper is on a descriptive explanation of the *phenomenon* of phonemic paraphasias, rather than supporting their occurrence with exact numbers.

3.3.2 Neural Network levels

The levels of representation used in the Abstract Neural Network in this paper are based on elements from the PALPA language processing model, as introduced in the previous chapter. First, a distinction should be made between comprehension and production routes; where comprehension and production are modeled sequentially from top to bottom in the PALPA model, in the Neural Network (Boersma et al., 2012), production is modeled from top to bottom and comprehension from bottom to top within the same network. The Abstract Neural Network of the present paper will apply the latter principle, but will also show limitations of the implication of bi-directionality.

Working with a neural network, means using the appropriate terminology to describe the different levels. Tables 3.1a and b contains a translation from PALPA to Neural Network labels for verbal and written communication, respectively. From now on, only the Neural Network terms will be used to refer to the different levels of representation.

Table 3.1a The Neural Network labels for the different verbal PALPA levels

Neural Network level	Production element in PALPA	Comprehension element in PALPA
Semantic System (SS)	SS (meaning database)	SS (meaning database)
Underlying Form (UF)	Phonological Output Lexicon (abstract word form database)	Auditory Input Lexicon (auditory word form database)
Surface Form (SF)	Phonological Level (phonemes of Dutch)	Auditory Analysis System (phonemes of Dutch)
Auditory Form (AudF)	Phonetic consonant and vowel features	Phonetic consonant and vowel features
Articulatory Form (ArtF)	Articulatory features	Articulatory features

Table 3.1b The Neural Network labels for the different written PALPA levels

Neural Network level	Production element in PALPA	Comprehension element in PALPA
Semantic System (SS)	SS (meaning database)	SS (meaning database)
Underlying Form (UF)	Graphemic Output Lexicon (graphemic word form database)	Visual Input Lexicon (graphemic word form database)
Surface Form (SF)	Graphemic Level (graphemes of Dutch)	Visual Analysis System (graphemes of Dutch)
Visual Form (VisF)	Letters from Dutch alphabet	Letters from Dutch alphabet

The Semantic System level is the same in both models; it contains conceptual knowledge about “people, objects, actions, relations, self, and culture acquired through experience” (Binder, Desai, Graves, & Conant, 2009). Concepts from the Semantic System are placed between double quotation marks. Single quotations marks are used to indicate that the concept of a particular segments or word is being discussed. The Underlying Form level of verbal processing contains abstract word forms of Dutch represented phonemically with symbols from the International Phonetic Alphabet (IPA) in both the production and comprehension route; UF word forms are placed between pipes. The Surface Form level of verbal processing also includes phonemic segments from the IPA in both directions; SF segments are placed between slashes. The IPA notations are drawn up following my own instinct as a native speaker of Dutch. Due to limitations of time, the Auditory Form level contains abstract auditory place, manner, and voice features for consonants, and place, height, and roundness features for vowels, instead of a more realistic that includes, for example, frequency. The Articulatory Form, in which articulatory execution is specified, will be left out of the networks due to their irrelevance for the present study as both participants have positively tested intact articulatory execution skills.

For written processing, the UF contains graphemes of Dutch, which are represented in double angle brackets The SF both also contains graphemes of Dutch, which are represented between single angle brackets. A distinction should be made between graphemes and letters; letters are the visual building blocks of written words and graphemes are letters and groups or letters that represent a phoneme. For example, the word 'ship' has four letters (s, h, i, and p) but three graphemes (<sh>, <i>, and <p>), as the 's' and 'h' together represent the phoneme /ʃ/. I would like to argue that during reading and writing, words are always pronounced inside a person's mind, and because graphemes are more closely related to phonemes than letters, I propose that reading and writing is processed in graphemes, rather than letters. Obviously, there are no Auditory and Articulatory Form levels for writing; instead, a Visual Form level is proposed which represents the visual building blocks of writing, that is the letters from the Dutch alphabet. For comprehension, this level includes the visual ability of being able to identify the letters on the basis of their shape, and for production, this level includes the motor ability to write down letters.

It is important to note that the UF level contains *word* forms, whereas the SF level contains single sound segments, which are, in turn, connected to phonetic features at the AudF level. This brings us to an essential element that is missing in the Neural Network as proposed by Boersma et al. (2012), namely that of *time.* I would like to propose a necessary Temporal Buffer (TB) between the UF and SF level. This Temporal Buffer stores either incoming word forms from the UF level or incoming sound segments from the SF level, until identification at the next level of processing is completed. Another function of this buffer is to maintain the order of the incoming elements. An example of how the Temporal Buffer is put into practice can be found in figures 3.2a to d in section 3.3.4 below.

3.3.3 Neural Networks and Executive Functions

Executive Functions are cognitive skills, that are defined by Elliot (2003) as “a set of complex cognitive processes requiring the co-ordination of several sub-processes to achieve a particular goal” (p. 49). These sub-processes include, among others, working memory and inhibition (Beck, Riggs, & Gorniak, 2009; Markovits & Doyon, 2004). Working memory is the ability to hold multiple representations in mind simultaneously, and inhibition is the ability to suppress irrelevant information and/or options. This relates to the function of the different Neural Network levels and the Temporal Buffer discussed in the previous section. Inhibition is necessary in order to choose the correct node or connection, and ignore those which are incorrectly activated or activated due to a semantic, word form, phonological, auditory, or articulatory within-level link. Within-level link activation is the process during which items or segments that are related to the target are co-activated with the target. Working memory is important for both buffer functions in the Network, as it enables the buffer to store and maintain the order of incoming Underlying word forms or Surface Form segments. How both functions relate to phonemic and graphemic errors will be discussed further in section 4.6.1.

3.3.4 Neural Network routes

Generally speaking, verbal and written comprehension follow the bottom-to-top route, and verbal and written production follow the top-to-bottom route in the Abstract Neural Network. Figures 3.2a to d show the verbal comprehension process of the Dutch word 'mok' (Eng. 'mug') in a healthy, non-brain-damaged Dutch individual represented in an Abstract Neural Network. For the purpose of explaining the process as well as possible, the Auditory Form level is included in the example below; note that this level will be left out in the data analysis Abstract Neural Networks in the next chapter. The Auditory Form level in these figures contain mere abstract phonetic place, manner and voice features, instead of, for example, formant[1] frequency values. Future research will include a more faithful realization of the auditory nodes among other things, see chapter 5 for more information on future ideas on the current study.

Figure 3.2a below shows that the activation of the semantic concept “mok” (Eng. 'mug') activates the Underlying Form |mɔk|, which is, subsequently, transferred to the Temporal Buffer where it is stored temporarily. The activation of UF |mɔk| is indicated with a clamped node. The other UF forms are randomly chosen phonologically related items which are only there to illustrate a small part of the auditory word form lexicon.

Figure 3.2a Verbal production of the Dutch word 'mok' modeled with an Abstract Neural Network – step 1

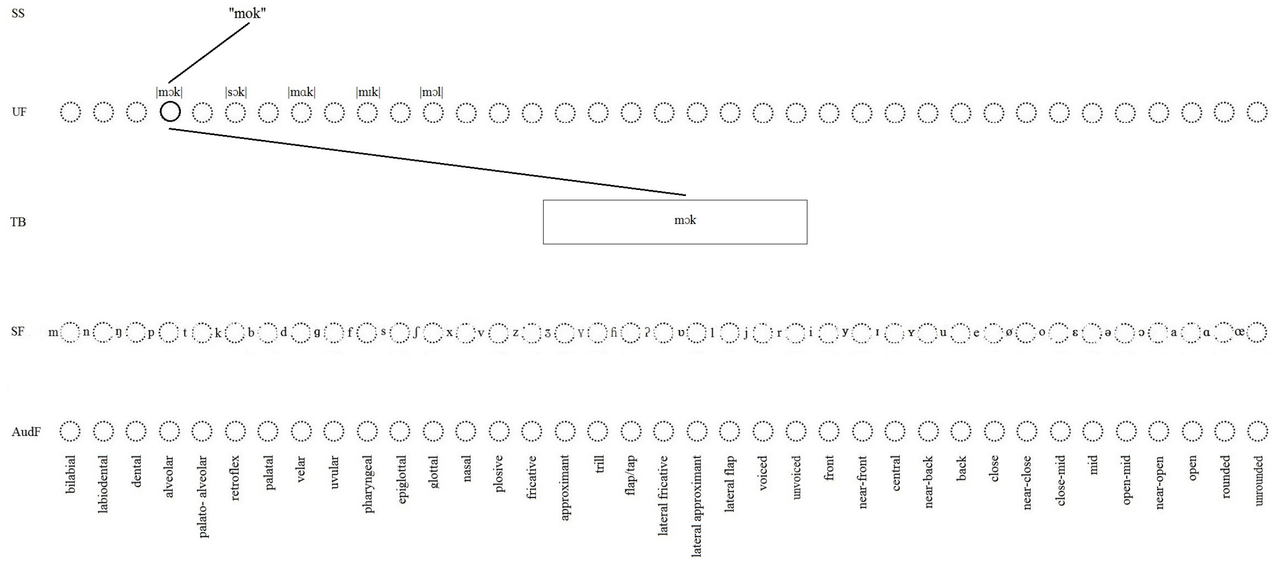


Figure 3.2b below shows the activation of the SF phonemic node /m/, resulting in the activation of the Auditory feature nodes [bilabial], [nasal], and [voiced] and the subsequent pronunciation of [m]. Activated nodes are again clamped.

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1 Distinguishing frequency components of human articulation.

Figure 3.2b Verbal production of the Dutch word 'mok' modeled with an Abstract Neural Network – step 2

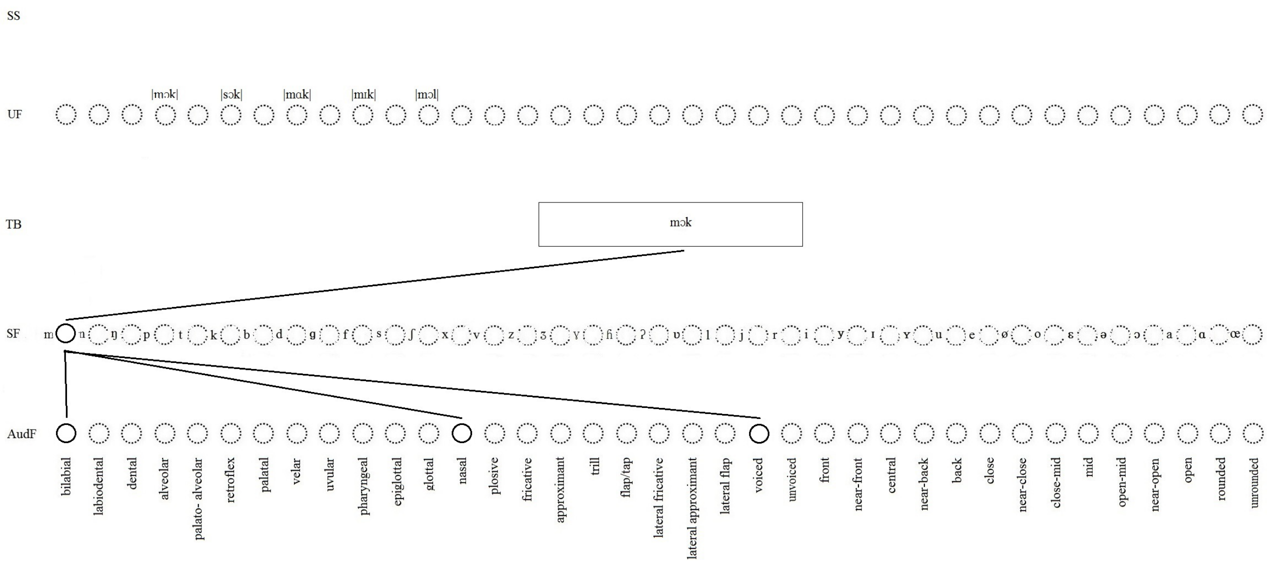


Figure 3.2c below shows the activation of the SF phonemic node /ɔ/, resulting in the activation of the Auditory feature nodes [back], [open-mid], and [rounded] and the subsequent pronunciation of [ɔ]. Activated nodes are again clamped.

Figure 3.2c Verbal production of the Dutch word 'mok' modeled with an Abstract Neural Network – step 3

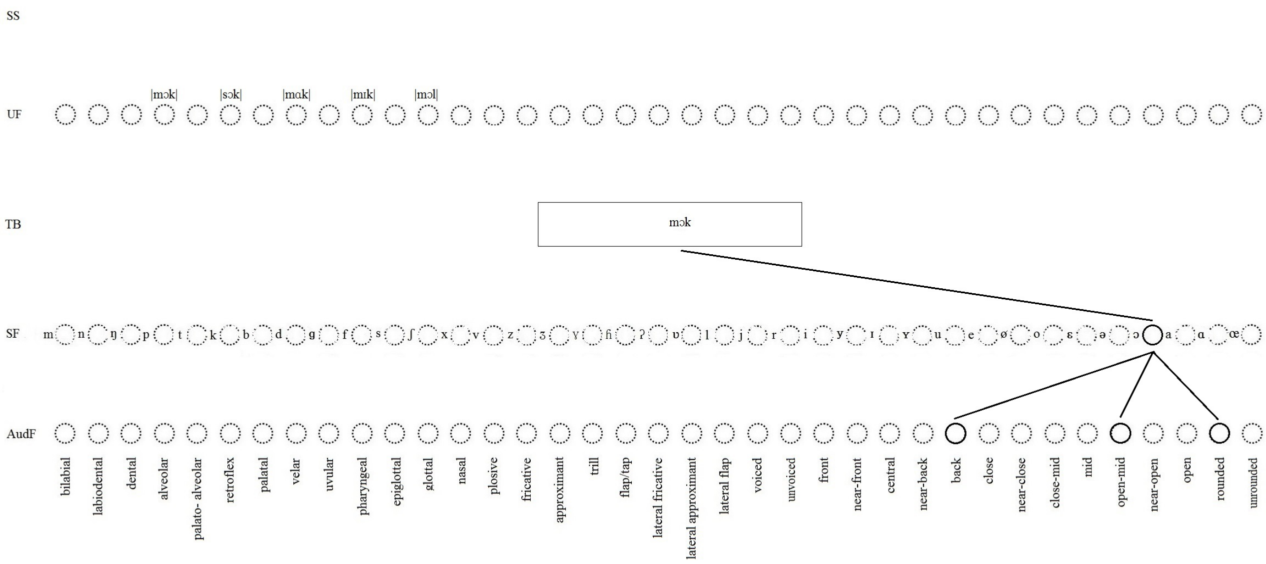
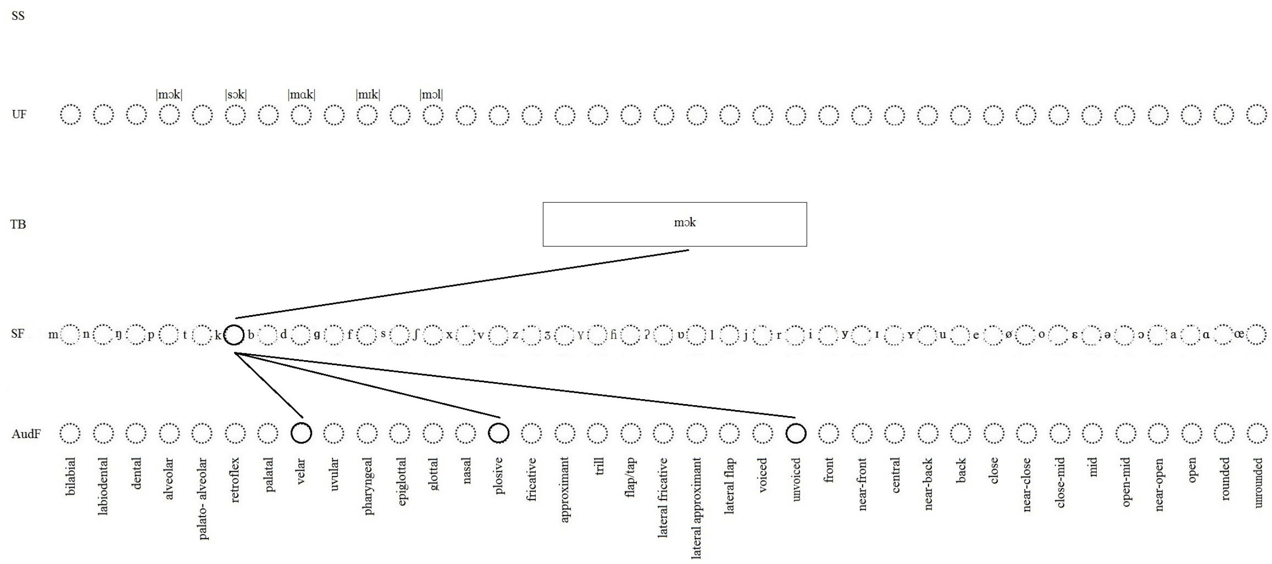


Figure 3.2d below shows the activation of the SF phonemic node /k/, resulting in the activation of the Auditory feature nodes [velar], [plosive], and [unvoiced] and the subsequent pronunciation of [k]. Activated nodes are again clamped. The final step finishes the production process, resulting in

the pronunciation of the Dutch word 'mok'. Note that the activation processes of the single segments illustrated here only take milliseconds.

Figure 3.2d Verbal production of the Dutch word 'mok' modeled with an Abstract Neural Network – final step



For comprehension, the reverse process can be modeled for the same Dutch word 'mok'. After activation of articulatory features, the Auditory features [velar], [plosive], and [unvoiced] are activated, resulting in the SF activation of /m/, which is stored in the Temporal Buffer, and, subsequently, activates all UF forms starting with an |m|. In the second step, the Auditory features [back], [open-mid], and [rounded] are activated, resulting in the activation of SF /ɔ/, which is stored, together with the |m|, in the Temporal Buffer as |mɔ|. Subsequently, the UF activation is narrowed down to all items starting with |mɔ|. The next step includes the activation of the Auditory features [bilabial], [nasal], and [voiced], resulting in the activation of SF /m/, which is stored, together with |mɔ|, in the Temporal Buffer as |mɔk|. Subsequently, the UF activation is narrowed down to all items starting with |mɔk|. When it is decided that |mɔk| is the target, UF |mɔk| activates the concept “mok” in het Semantic System. How it is decided whether an UF is the target depends on whether 'mok' is produced in isolation or in a sentence. When it is produced in isolation, the decision is made when no more additional segments are activated. When it is produced in a sentence, more complex sentence processing rules apply, which will not be discussed here.

In addition, one of the characteristics of the Abstract Neural Network is that all nodes within and *between* levels of representation are fundamentally connected, albeit with different weights. A language user has knowledge of relationships between adjacent levels in the form of sensorimotor knowledge for the relationship between the Articulatory level and the Auditory level, cue knowledge for the relationship between the Auditory level and the Surface Form level, and phonological knowledge for the relationship between the Surface Form level and the Underlying Form level (Boersma et al., 2012). A language user also has "knowledge about the restrictions *within* levels: the articulatory, structural, and morpheme-structure constraints" for the Articulatory, Surface Form, and Underlying Form level respectively[2] (Boersma et al., 2012, p. 2). These restrictions include a set of language rules that apply to the phonology and phonetics of a language and are different for every language. In a Neural Network as proposed by Boersma et al. (2012), this knowledge is represented as "a long-term memory consisting of connection weights" (p.2). The connection weights thus indicate optionality, in case of strong(er) weights, or restrictions, in case of weak(er) weights, of connections between nodes from two adjacent levels of representation. This means that, for example, when UF segment |z| is to be realized as either SF /z/ or as /s/ (SF /s/ in case of devoicing), the connections between UF |z| and SF /z/ and between UF |z| and SF /s/ are strong, whereas the connection between UF |z| and SF /k/, for example, is present, but with a value of zero.

The connections in a Neural Network also relate to the biological neuron in our brain, which may "establish up to 10,000 connections with other neurons" (Potagas, Kasselimis, and Evdokimidis, 2013, p. 27). This characteristic of the Abstract Neural Network is an important element of the explanation of the occurrence of phonemic paraphasias in individuals with aphasia, which will be further discussed in section 4.5 of the next chapter.

3.3.4.1 Neural Network routes and language tasks

As for the clinical application of the Neural Network, levels and connections from the Neural Network can be evaluated by subjecting them to different language comprehension and production tasks. The following tasks and accompanying routes in the Neural Network are important for understanding the data analysis; the color name behind the routes correspond to the route color in figure 3.3 below:

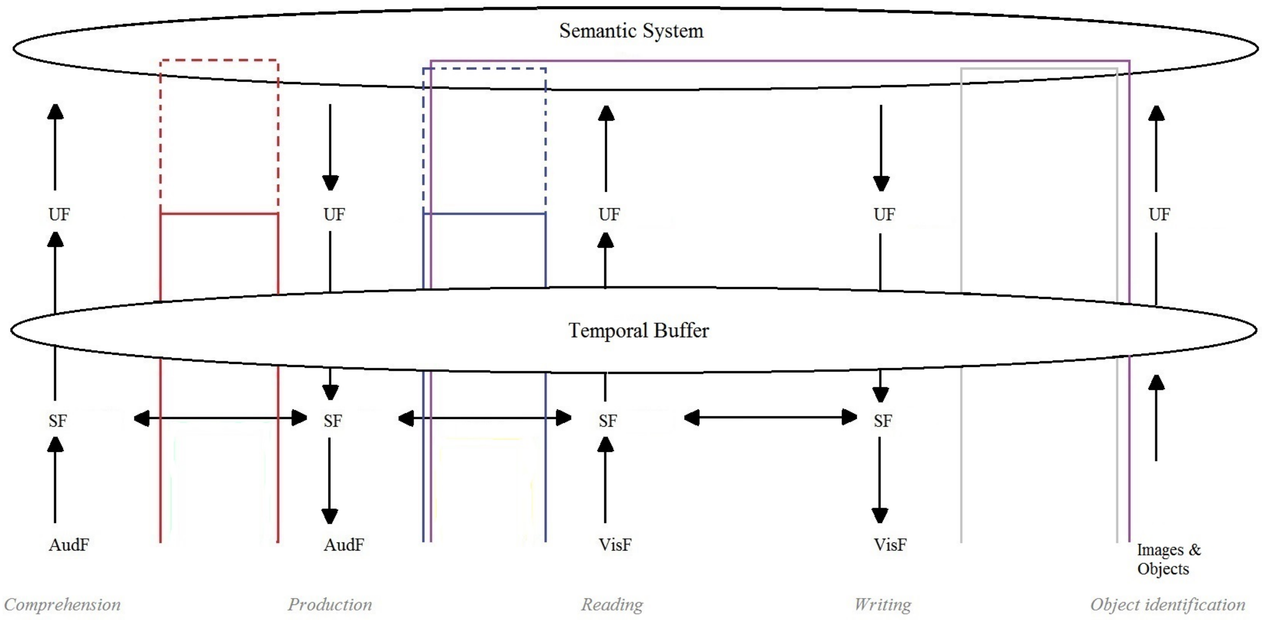
- Word repetition: AudF → SF → UF → (SS →) UF → SF → AudF (red);
- Reading words aloud: VisF → SF → UF → (SS →) UF → SF → AudF (blue);
- Verbal picture naming: Images & Objects → UF(Visual Object Recognition) → SS → UF → SF → AudF (purple);
- Written picture naming: Images & Objects → UF(Visual Object Recognition) → SS → UF → SF → AudF (grey).

With word repetition and reading words aloud, the Semantic System (SS) is in parenthesis because

[2] No constraints were proposed by Boersma et al. (2012) for the Auditory level. However, continuing the same way of reasoning, it might be assumed that knowledge about the Auditory level comes in the form of auditory constraints.

it is not necessarily part of the route, but doing these tasks without activating the meaning (with an intact SS) of the item presented is almost impossible. For the naming tasks, I would like to argue that the Visual Object Recognition, as presented in the PALPA model, is an Underlying Form. I propose that an Underlying word form is necessary to access the Semantic System and retrieve semantic information of the identified object or image. Figure 3.3 below contains a schematic overview of the different parts of the Abstract Neural Network involved in the tasks listed above.

Figure 3.3 Schematic overview of language tasks



3.3.4.2 Neural Network routes and bi-directionality

It was mentioned earlier in this paper that the Abstract Neural Network used here will apply Boersma et al.'s (2012) top-to-bottom production and bottom-to-top comprehension modeling and that limitations of the implication of bi-directionality will be touched upon. Figure 3.3 above provides a sneak peak into the limitations of the bi-directionality principle in impaired language processing.

Boersma et al. (2012) argue that the same knowledge is used for both comprehension and production of speech and that the knowledge between the levels of representations in a Neural Network is bi-directional. This means that, for example, a sound that is comprehended with sounds qualities A and B, will also be produced with the same qualities A and B. Boersma et al. (2012) furthermore argue that “bi-directional connections are known to provide stability in neural network models”, meaning that, “the strength of the connection weight from node A to node B equals the weight from node B to node A” (p. 7). This principle of bi-directionality thus implies that when the weight of the connection between node A and B increases or reduces, the weight of the connection between B and A increases or reduces equally.

When considering impaired language abilities, Boersma et al.'s (2012) argument about how knowledge between levels is bi-directional seems insufficient. When applying the principle of bi-directionality to a person with impaired language skills, it predicts that the same deficits should occur between, for example, the AudF and SF level in both production and comprehension. This implies that when, for example, the connection between the AudF phonetic feature [nasal] and SF phoneme /m/ is temporarily broken or reduced in weight to such an extent that the activation of AudF phonetic features [nasal], [bilabial], and [voiced], activates, for example, the phoneme /b/ at the SF level, the Dutch word 'mok', might be interpreted in the comprehension process as 'bok' (Eng. 'billy' or 'male goat'). The other way around, according to the principle of bi-directionality, the broken connection between SF phoneme /m/ and AudF phonetic feature [nasal], should cause any attempt at producing the Dutch word 'mok' to be unsuccessful and change the outcome into [bok]. The /m/ to /b/ conversion occurs because /b/ is the only phoneme in Dutch that shares the phonetic features [bilabial] and [voiced] with /m/.

The impaired top-down production can be seen in the phonemic paraphasias and paragraphias discussed and modeled in the next chapter of this paper. One way verbal and written comprehension was tested was by presenting an item either verbally or in writing to the patient, who then had to choose the picture that matched the target item. Among the distractor pictures was one phonological distractor, one semantic distractor, and one unrelated distractor. For example, with the verbally presented item 'mouse', the distractor pictures would include 'house' (phonological distractor), 'rat' (semantic distractor), and 'television' (unrelated distractor). Both patients never chose the phonological distractor to match the target item, meaning that the target item was always processed throught the ArtF, AudF, SF, TB, and UF level (for listening), or the VisF, SF, and UF level (for reading), without phonological impairments. The bi-directionality prediction thus seems valid because both patients included in this study were tested on verbal and written comprehension, and both had intact phonological comprehension[3].

3.4 Summary

This chapter started with a brief history of language models, followed by an introduction and formalization of the Neural Network as used in the next chapter for analysis. Specific elements, such as the implication of bi-directionality and the fact that all nodes within and between levels are

[3] No errors were made during the tests with phonological distractors; both patients did, however, had problems with more complex syntactic test items.

connected, were highlighted because of their relevance for understanding the data analysis. The next chapter will be on the methods used in this study.

4. Methods

This section will provide information on the participants included in this study, the materials used and procedures followed, and overview of the data, followed by a data analysis, discussion and, conclusion drawn up on the data.

4.1 Participants

For this study, data on phonemic paraphasias and paragraphias was taken from two male patients. Specific patient data can be found in table 4.1 below. Both suffered from a left hemisphere iCVA in the ACM area of the brain; an ischemic CVA in the ACM area is the medical term for a stroke, and is characterized by the sudden loss of blood flow to the middle cerebral artery (Lat. Arteria Cerebri Media) in a person's brain (Bastiaanse, 2011). The patients' aphasia diagnoses were based on the results from a battery of standardized language tests at the Rijndam Rehabilitation Center in Rotterdam. In most studies the minimum number of months post onset (tpo/month) for aphasia patients is set at three, because in the first three months after suffering from a CVA, a person's damaged brain functions may still improve or, in some cases, even fully recover; after three months, however, the chance of improvement and/or recovery will decrease, and approximate zero rapidly. The impairments aphasics show after they are minimally three months post onset, are considered to be *stable impairments.* Because the focus of this paper is on phonemic paraphasias and paragraphias as produced by brain-damaged individuals in general, without relating the errors to a specific moment post onset, this tpo boundary is not used as an inclusion criteria here.

Table 4.1 Patient data

Patient number	Gender	Age	Lesion	Tpo/months
1	Male	77	iCVA ACM left	6
2	Male	57	iCVA ACM left	2

Note: ACM = arteria cerebri media (middle cerebral artery).

4.2 Materials

The materials used for this paper are tests taken from the standard and additional test battery from Rijndam, which I administered myself. Phonemic paraphasias and paragraphias were collected from test data from the *Boston Benoem Taak* and the *Comprehensive Aphasie Test*. The middle column of table 4.2 below contains the tasks the phonemic paraphasias and paragraphias were taken from per patient; the number in parenthesis is the number of weeks post onset of the CVA the task was administered. The final column shows the skills that are tested in each task. Due to time post onset, language impairments, and therapy schedule, not all tests are administered to both patients.

Table 4.2 Patients' test data

Patient number	Tests (tpo/weeks)	Test components
1	1st CAT-NL (1) 2nd CAT-NL (8)	Word repetition, reading aloud, and verbal naming Word repetition, reading aloud, and verbal naming
2	BBT (1)	Written and verbal naming

The *Boston Benoem Taak* (BBT) is a neuropsychological assessment tool consisting of 60 line drawings, graded in difficulty of the represented words, to measure word retrieval. The second task is the Dutch adaptation of the CAT; the *Comprehensive Aphasia Test* (CAT) is a speech and language assessment tool which includes a cognitive screen as well as a comprehensive language test battery. This battery includes, among others, tests on reading aloud, repetition, and verbal naming. All three tasks consist of multiple items; the first sixteen items of all tasks are everyday items, varying in length, word frequency, and imageability. The second set of items consists of three longer, more complex words, and the third set of items consists of three short function words.

4.3 Procedures

Both patients were tested in a one on one test situation in a quiet room. All verbal answers were recorded with a voice-recorder. For both tests the items were presented in a set order. For the BBT the patient was told to name the object represented on the page in one word. For the written version of the BBT, the patient was told to write down one word that describes the object on the page best. For the repetition task of the CAT-NL, the patient was told that the tester would say a word and that he had to repeat it as well as possible. For the reading aloud task the patient was simply instructed to read the word out loud. Finally, for the verbal naming task, the patient was asked to name the object using only one word.

4.4 Data overview

In this section, the phonemic paraphasias and paragraphias found in the test data from the two participants will be presented. Every error type, that is, substitution, addition, omission, and metathesis, will be discussed separately. Each section contains a table per patient with an overview of the errors collected. In each section, table 'a' contains the errors made by patient 1, and table 'b' contains the errors made by patient 2. In the table for patient 1, the T1 and T2 in the final column stand for test moment 1, at one week post-onset; and test moment 2, at eight weeks post-onset. The tables contain target items, errors made, phonological processes involved in the errors, and information on the language skill tested.

It should be mentioned that only 'clean errors' were selected from the data. 'Clean errors' are errors that contain only one error type. People with aphasia also make errors which contain multiple error types, for example both metathesis and substitution(s). This paper will only discuss clean errors, because it is not always clear which error types play a role in non-clean errors. If the error type is ambiguous, the error can be modeled in more than one way, making it more difficult to model and to draw conclusions.

Note that, in some cases, phonemic paraphasias and paragraphias cause the target word to become a different, existing word in Dutch; this process is identified as a 'word selection error'. When phonemic paraphasias and paragraphias cause the target item to change into a non-existing Dutch word, it is called 'word production error'. This distinction is important for the error modeling in section 4.5, which includes an overview of the data.

4.4.1 Substitution

A total of 36 phonemic substitutions and five graphemic substitutions were collected from the two patients. Table 4.3a. below, contains all phonemic errors collected from patient 1, including place, manner, voicing, and rounding specification of the target phoneme(s) and its substituted counterpart(s). At test moment 1, patient 1 made eighteen substitution errors, and ten errors at test moment 2. Among the substituted target phonemes consonant place 'alveolar' occurs most often, namely five times at T1 and seven times at T2. Among the substitutions consonant place 'alveolar' occurs most often as well at T1, four times, and at T2 'alveolar' and 'velar' both occur three times. Furthermore, among both the target phonemes and the substitutions the consonant manner feature 'plosive' occurs most often, five and nine times at T1, and six and six times at T2, respectively. Among the substituted target vowels and the substituted counterparts at T1, vowel place is most often 'front', occurring five and seven times respectively, and vowel height is '(mid-)open' for the targets, occurring five times, and '(near-/mid-)close' for the substitutions at T1, occurring eight times. Vowel place and height statistics are not relevant for T2, as only three vowels are substituted at that test moment. The phonological processes involved in the consonant substitutions most, are 'consonant fronting', or C fronting, at T1, occurring seven times, and 'consonant backing', or C backing', at T2, occurring five times. The phonological processes involved in the vowel substitutions most is 'closing', occurring five times.

In the substitution data set from patient 1, there is one phonological process, called monophtongization, which I would like to explain briefly. Occurring twice in the substitution data from patient 1, monophtongization is the process of changing a diphtong into a monophtong. In this case, both instances of monophtongization involve changing an /ɛɪ/ into an /e:/. In the IPA vowel chart, the /e/ lies about in between the /ɛ/ and the /ɪ/, which might be an explanation for this substitution.

Of the substitutions in the table below, /sty:r/, /bəsɣɪkɪŋ/, /dɛk/, /vi:la/, /slɛɪt/, /ɣrɔf/, /kɛrk/, /ka:n/, /sɣɛlt/, /sɣɪlt/, /ɔnbərɛɪtba:r/, /ku:k/, /bu:t/, /to:n/, /ki:m/, /bu:k/, /krɑt/, and /jɑm/ are considered word selection errors, thirteen of which were made at T1 and five at T2, whereas the other substitutions are all word production errors.

Table 4.3a Patient 1 – phonemic substitutions

Target	Target specification	Substitution	Substitiution specification	Phonological process	Skill tested
k**a:**mər**a**	fr op unr	k**e:**məra ka:mər**o**	fr cl-m unr ba cl-m r	closing V backing + closing + rounding	T1 reading aloud
sl**œ**r	alv lat-ap v fr op-m r	sl**i:**r sl**y:**r s**ty:**r	fr cl unr fr cl r alv pl unv ba cl r	closing + unrounding closing stopping + devoicing V backing + closing	
m**ɑ**ʃ**i**nə	ba op unr fr cl unr	m**i**ʃ**y**nə	fr cl unr fr cl r	V backing + closing rounding	
b**ɔ**rst	ba op-m r	b**ɛ**rst	fr op-m unr	V fronting + unrounding	
vi**j**a	pal appr v	vi**l**a	alv lat-ap v	C fronting	
bəs**l**ɪ**s**ɪŋ	alv lat-ap v alv fri unv	bəs**ɣ**ɪ**k**ɪŋ	ve fri v ve pl unv	C backing + frication C backing + stopping	
jɛk	pal appr v	**d**ɛk	alv pl v	C fronting + stopping	

ta:**f**əl	alv pl unv	ta:**p**əl	bilab pl unv	C fronting	T1 repetition
sl**ɛɪk**	ve pl unv fr op-m unr → n-fr n-cl unr	slɛɪ**t** sl**e:**k	alv pl unv fr cl-m unr	C fronting monoph-tongization	
dœr	alv pl v	**b**œr	bilab pl v	C fronting	
ɣr**u:**f	ba cl r	ɣr**ɔ**f	ba op-m r	opening	
pɛrk	bilab pl unv	**k**ɛrk	ve pl unv	C backing	
ɔnbərɛɪ**k**ba:r	ve pl unv	ɔnbərɛɪ**t**ba:r	alv pl unv	C fronting	
ɦu:t	gl fri v	**b**u:t	bilab pl v	C fronting + stopping	T1 verbal naming
ku:**p**	bilab pl unv	ku:**k**	ve pl unv	progressive assimilation	T2 reading aloud
t**u:**n	ba cl r	t**o:**n	ba cl-m r	opening	
ti:m	alv pl unv	**k**i:m	ve pl unv	C backing	
te:le:fo:n	alv pl unv	**ɦ**e:le:fo:n	gl fri v	C backing + voicing + frication	
di:rɛks**i:**	fr cl unr	di:rɛks**ə**	ce m r	centralization + rounding	
pra:i**f**əsi:	lab-d fri unv	pra:i**s**əsi:	alv fri unv	regressive assimilation	
di:**vi**:**d**ɛnt	fr cl unr lab-d fri v alv pl v	d**e:p**i:**s**ɛnt	fr cl-m unr bilab pl unv alv fri unv	opening stopping + devoicing frication + devoicing	
krɑ**p**	bilab pl unv	krɑ**t**	alv pl unv	C backing	T2 verbal naming
lɑm	alv lat-ap v	**j**ɑm	pal appr v	C backing	
ɦu:**t**	gl fri v alv pl unv	**b**u:**k**	bilab pl v ve pl unv	C fronting + stopping C backing	

Table 4.3b. below contains the eight phonemic and five graphemic substitutions made by patient 2 during the verbal and written version of the BBT. With regard to the phonemic substitutions, most substituted targets and the substitutions contain the consonant place feature 'alveolar', occurring five and seven times respectively. The consonant manner feature 'lateral approximant' occurs most often, that is, four times among the substituted targets, whereas 'fricative' occurs most often, that is, four times, among the substitutions. As for the graphemic substitutions, all five errors involve different orthographic processes. Consonants are substituted at the onset and coda of a syllable; clusters are (partially) substituted, meaning that one or more segments from a cluster are substituted; and, finally, two types of consonant harmony occur. Consonant harmony is a type of 'long distance' phonological assimilation, in which a consonant becomes similar to another consonant within the same word. The term 'long distance' refers to the fact that the assimilation involves consonants that are separated by other segments (either vowels, consonants, or both). The first case of harmony in the data set is regressive harmony, with which the following segment <s> influences two preceding ones, namely <c> and <t>. The second case is progressive harmony, in which the reverse process happens, and preceding <k> influences following <f>. All substituted segments in both the verbal and written version of the naming task are consonants.

Of the phonemic substitutions, only the first one in the table is a word selection error, and the others are all word production errors. For the graphemic substitutions, although the <c> in 'helicopter' can also be pronounced as a /k/ in Dutch, it is not a valid substitution in writing; I would, therefore, like to classify all as word production errors.

Table 4.3b Patient 2 – phonemic and graphemic substitutions

Target	Target specification	Substitution	Substitution specification	Process	Skill tested
bo:**m**	bilab nas v	bo:**n**	alv nas v	C backing	verbal naming
f**l**œyt	alv lat-ap v	f**r**œyt	alv tr v	unknown	
ka:no	ve pl unv	**s**a:no	alv fri unv	C fronting + frication	
vʏlka:n	lab-d fri v alv lat-ap v	**sʏs**ka:n	alv fri unv	prevocalic voicing / assimilation	
i:**ɣ**lo:	ve fri v	i:**s**ro:	alv fri unv	C fronting + devoicing	

kɑk**t**ʏs he:**l**i:kɔptər pe:**l**i:ka:n	alv pl unv alv lat-ap v alv lat-ap v	kɑk**ɣ**ʏs he:**d**i:kɔptər pe:**d**i:da:n	ve fri v alv pl v alv pl v	C backing + frication stopping stopping	
heli**k**opter padde**n**stoel k**link** ca**ct**us muilkor**f**		heli**c**opter padde**l**stoel k**rips** ca**ss**us muilkor**k**		onset C substitution coda C substitution (partial) cluster substitution consonant harmony consonant harmony	written naming

4.4.2 Addition

A total of eight phonemic additions and seven graphemic additions were collected from the data sets from the two patients. The following phonological processes were identified:

- C or V epenthesis: the addition of a consonant or vowel between two segments;
- Coda C or V addition: the addition of a consonant or vowel in word final position;
- Onset C addition: the addition of a consonant in word initial position;
- Syllable addition: the addition of an entire syllable in the middle of a word;
- Coda syllable addition: the addition of an entire syllable in word final position.

As can be seen in the data set from patient 1 in table 4.4a below, C epenthesis occurs and coda addition occur most often, namely both four times, while the other processes occur only once or twice. In the sample, four vowels are added in total. The additions do not violate any of the phonological rules for Dutch, that is, the consonant and vowel combinations that are present in the addition errors, such as /str/, /ɣəʊ/, /tɛkt/, and /ɑlm/, all occur in Dutch. Note how in the addition /fɑlmi:li:/ the target /a:/ became a more front and shortened /ɑ/, before the /l/ was inserted. The first seven additions are all word production errors, and the last one is the target's plural in Dutch, and will therefore be considered a word selection error.

Table 4.4a Patient 1 – phonemic additions

Target	Addition	Process	Skill tested
a:ntrɛkən	a:n**s**trɛkən	C epenthesis	T1 reading aloud
ta:fəl ɑrti:kəl fa:mi:li: ɔndərʋɛɪs	ta:fəl**ə** **p**ɑrti:kəl fɑ**l**mi:li: ɔndər**ɣə**ʋɛɪs	coda V addition onset C addition C epenthesis + V fronting syllable addition	T1 repetition
pa:ra:ply	pa:ra:ply**m**	coda C addition	T2 reading aloud
ɑrti:kəl kɑrnavɑl	ɑrti:**tɛ**k**t**əl kɑrnavɑl**s**	C & V epenthesis coda C addition	T2 repetition

As reported in table 4.4b below, a total of seven graphemic additions were found in the written BBT from patient 2. Two of three instances of coda C addition and the instance of coda syllable addition result in the formation of the plural of the target word. Two cases of C epenthesis create a new cluster, whereas the third case of C epenthesis adds to an existing cluster. All additions include consonants only.

'Fluits' and 'sltatief' are the only two word production errors here, the other five are all existing words in Dutch, and therefore considered word selection errors.

Table 4.4b Patient 2 – graphemic additions

Target	Addition	Process	Skill tested
fluit slak klopper statief palet	fluit**s** sla**n**k klopper**s** s**l**tatief pal**l**et	coda C addition C epenthesis coda C addition C epenthesis C epenthesis	written naming

bloem bezem	bloem**en** bezem**s**	coda syllable addition coda C addition	

4.4.3 Omission

A total of eleven phonemic and four graphemic omissions were collected from the data sets of the two patients. The following phonological processes were identified:

- Cluster reduction: deletion of a consonant from a target cluster;
- Coda V or C deletion: deletion of a vowel or consonant in word final position;
- Syllable deletion: deletion of a syllable;
- Coda syllable deletion: deletion of a syllable in word final position;
- C deletion: deletion of a consonant in word-internal position;
- Schwa deletion: deletion of an unstressed vowel.

As can be seen from table 4.5a below, for patient 1, the first test moment includes mostly coda deletion, whereas the second test moment includes mostly cluster reduction processes. The omissions resulting in /ka:mər/, /bɑkkər/, and /kɑn/ are word selection errors, whereas the other six are all word production errors.

Table 4.5a Patient 1 - phonemic omissions

Target	Omission	Process	Skill tested
ka:**məra:** bɑkər**ɛɪ**	ka:mər_ ka:_ _ra: bɑkkər_	coda V deletion syllable deletion coda V deletion	T1 reading aloud
kɑn**s** ɣət**r**øzəlt	kɑn_ ɣət_øzəlt	coda C deletion cluster reduction	T1 repetition
sl**œ**r lʏ**n**ʃ	sl**œ_** lʏ_ʃ	coda C deletion cluster reduction	T2 reading aloud
ɣətrøz**əl**t f**ɑm**i:li:	ɣətrøs_ _t f_ _i:li:	devoicing + cluster reduction + schwa deletion cluster reduction	T2 repetition

A total of two phonemic omissions and four graphemic omissions were found in the data set from patient 2, see table 4.5b below. Cluster reduction and syllable deletion both occur twice. In both cases of syllable deletion, the 'en' morpheme that is deleted, is the plural form of the preceding segment in the target word, which is necessary for the correct interpretation of the word. Although 'plantrek' and 'tandborstel' seem to be a compound of two separate existing Dutch words, namely 'plant' and 'rek', and 'tand' and 'borstel' respectively, they are in the writing of patient 2 presented as one word, I would, therefore, like to argue these two are word production errors. All but one, namely /bu:m/, are word production errors.

Table 4.5b Patient 2 – phonemic and graphemic omissions

Target	Omission	Orthographic process	Skill tested
b**l**u:m rɔlt**r**ɑp	b_u:m rɔlt_ɑp	cluster reduction cluster reduction	verbal naming
plant**en**rek tand**en**borstel mask**er** krak**el**ing	plant_ _rek tand_ _borstel mask_ _ krak_ _ing	syllable deletion syllable deletion coda syllable deletion schwa + C deletion	written naming

4.4.4 Metathesis

Metathesis is a phenomenon that does not occur very often as a clean error; it mostly occurs in combination with other error types. In the current data set, I was able to find a total of six clean phonemic metathetic errors in the data sets of both patients.

Table 4.6a below includes the phonetic metathetic errors by patient 1 at T2, as there were no metathetic errors in T1 . The errors include adjacent segment metathesis in the first example, onset to coda metathesis in the second example, cluster segment to coda metathesis in the third example, and metathesis from a coda segment to word-interior position, moving the second to last segment to coda position. All errors are word production errors.

4.6a Patient 1 – phonemic metathesis

Target	Metathesis	Skill tested
mi:ra:k**əl**	mi:ra:k**lə**	T2 reading aloud

ku:**p** s**p**o:**k** ɛlə**bo**:**ɣ**	**p**u:**k** s**k**o:**p** ɛlə**ɣ**bo:**_**	

A total of two graphemic metathetic errors were found in the data set of patient 2, see table 4.6b below. The first case includes a kind of general metathesis in which four out of six segments are metathesized, and the second case includes the metathesis of the second cluster segment with the coda segment of the second syllable. Both errors are word production errors.

Table 4.6b Patient 2 – graphemic metathesis

Target	Metathesis	Skill tested
racket rols**t**oe**l**	**karec**t rols**l**oe**t**	written naming

4.4.5 Data summary

With substitution errors there seems to be a tendency for 'alveolar' and 'plosive' segments to be the substituted elements for all verbal substitutions of both patients. More consonants were substituted at both test moments, and more vowels were substituted at T1 than at T2. The phonological process that occurred most went from consonant fronting at T1 to consonant backing at T2. This could imply that people with aphasia who produce phonemic paraphasias and are still in their first (few) week(s) post-onset, use segments that are produced more front in the mouth, possibly due to ease of articulation.

The phonemic additions by patient 1 and the graphemic additions by patient 2 were mostly consonants. In the phonemic errors, consonant additions in word-interior and coda position occurred an equal number of times; the graphemic additions occurred mostly in coda position.

At T1 of patient 1, most omissions were coda deletions, whereas cluster reduction occurred most often at the T2 of patient 2 as well as in the verbal naming of patient 2. The written naming of patient 2 included syllable deletions most. The syllable omissions in both verbal and written naming were all non-stressed syllables, which occur very often in Dutch. For the metathetic errors, no generalizations can be made, except that no such errors occurred at T1 of patient 1 and verbal naming of patient 2.

4.4.6 Overview

It should be mentioned that the least errors in the data set from patient 1 comes from the verbal naming task. At T1, patient 1 was almost unable to name any items, but used circumlocution to describe the objects; at T2 patient 1 named most items correct and used circumlocution for some. The fact that verbal naming was significantly harder for patient 1, compared to repetition and reading aloud, may be explained by looking at the PALPA model. Patient 1's verbal and written input, that is, auditory and written comprehension, are intact; meaning that when hearing or reading a word, as with repetition and reading aloud, respectively, the correct Underlying Form is activated via the Articulatory Form, Auditory Form, and Surface Form successively for verbal comprehension, and via the Visual Form and Surface Form successively for reading. The Underlying Form that is identified in comprehension, either written or verbal, is subsequently transferred and used in the output lexicon, that is, Underlying form for production. With naming for patient 1, the Underlying Form had to be activated via the Images and Object Recognition mechanism and Semantic System, respectively. Considering that Object Recognition was intact, it may be concluded that patient 1 was (partially) unable to name objects due to the impaired connections between the Semantic System and the Underlying Form in the production route. The impaired connections between the SS and UF prevented patient 1 from accessing the Underlying Form of the object he had to name, which is necessary for verbal production.

Table 4.7 below shows an overview of the phonemic and graphemic errors discussed in the previous sections. At test moment one for patient 1, substitution occurs most often, as opposed to test moment 2, where omissions occurs most often. In the verbal naming of patient 2, substitutions also occur most often, whereas additions occur most often in the written naming task. Less errors occurred at test moment 2 (T2: 23 errors) of patient 1, than in test moment 1 (T1: 30 errors); and less errors occur in the verbal naming of patient 2 (V: 10), than in the written naming (W: 18).

Table 4.7 Phonemic and graphemic error data overview

Error type	Patient 1	Patient 2
Substitution	T1: 18 T2: 10	V: 8 W: 5
Addition	T1: 5 T2: 3	V: 0 W: 7
Omission	T1: 5 T2: 6	V: 2 W: 4

Metathesis	T1: 0 T2: 4	V: 0 W: 2

Although it is expected that less errors would occur at T2 than at T1, the difference for patient 1 is not significant (p=0.30; t=0.61); the difference between reading and writing for patient two is not significant either (p=0.20; t=0.93).

4.5 Results

In this section, the phonemic paraphasias and paragraphias that will be modeled in this section will be described using elements from the Abstract Neural Networks. A distinction has been made between word production errors and word selection errors in order to be able to model different error types and locations. Although opinions may differ on localization and definition of certain error types, this paper applies the principle of word selection errors, and the modeling thereof between the Semantic System and the UF level, to those errors that become an existing word, different from the target item. The definition of 'different' here is used in the broadest sense in that it also includes plurals or other inflectional markings of verbs and nouns. The localization of substitutions, additions, omissions, and metatheses will be discussed after the connection characteristics have been illustrated.

Connection weights in Neural Networks can 'learn' on the basis of experience, however, “they change only slowly over the months and years as the child is acquiring her language” (Boersma et al., 2012, p. 13). Thus, in theory, the more experienced a person gets in using a language the more the connection weights should stabilize. Although people never stop learning a language, connection weights are assumed to stabilize over time. This stabilization will result in strong connections between corresponding segments, for example between UF |s| and SF /s/, or between UF |i| and SF /i/ and /ɪ/ as both realizations occur in normal speech. The stabilization may be disrupted due to, for example, damage to the language areas in a person's brain; in the Neural Network, connection weights may then subsequently alter. How and where these alterations take place in the Neural Network, will be explained next.

In the Neural Networks containing substitution errors below, it is suggested that substitution errors occur between the Surface Form level and the Auditory Form level for verbal production, and between the Surface Form level and Visual Form level for written production. The reason for this localization is because both levels contain single segments only, either graphemes or phonemes, and substitution is a process applied to single segments. Substitutions cannot be located between the

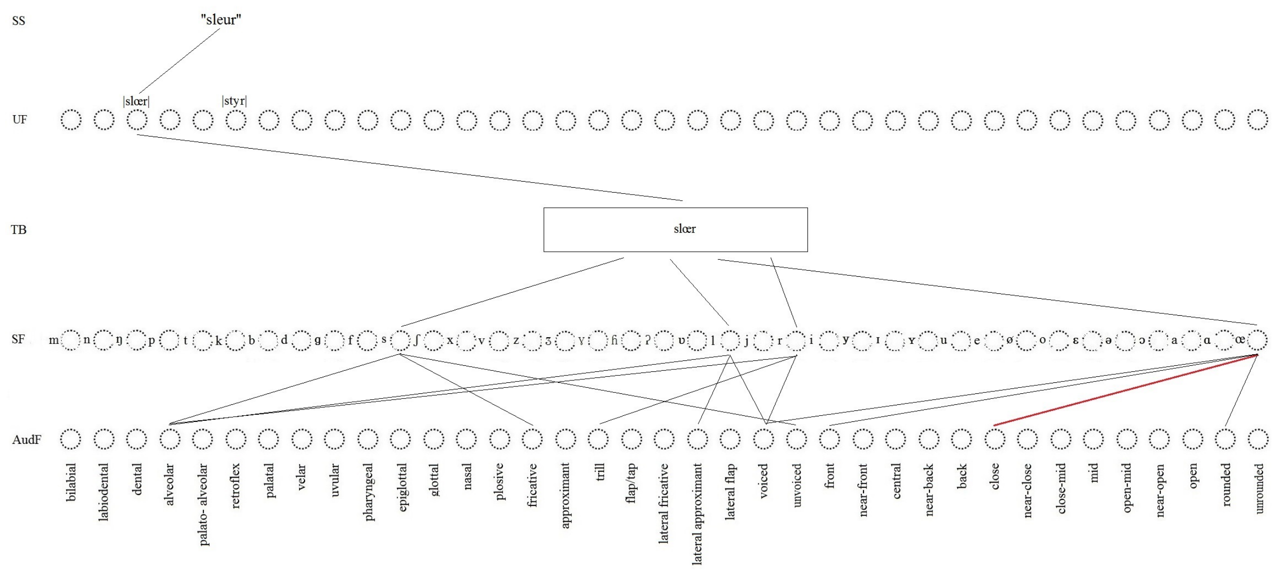
Underlying Form level and the buffer, because the word form activated in the UF is transferred as a whole to the buffer, see previous chapter for a Neural Network on the production of a single word. Omission and metathetic errors are both assumed to be localized at the Temporal Buffer level. As argued before, the Temporal Buffer has two functions; the first is to keep UF or SF segments in memory, and the second is to maintain the order of the segments. Omission errors originate from a temporary impairment in the memory function, preventing activation spreading of one or more segments to the next level of representation. Metathetic errors originate from a temporary impairment at the second function of the Temporal Buffer, namely the maintenance or the order of the incoming segments. Both functional impairments to the Temporal Buffer, that is, the memory function and order retention, must be assumed to be temporary, because otherwise all items, in both production and comprehension, must contain omission and/or metathetic errors. Additions are the only within-level errors, as they are assumed to originate from the SF level. As mentioned before, all nodes of one level are also connected. For the SF level, this means that the activation of a particular clamped node may slightly activate unclamped nodes that, according to the phonological rules of a language, combine with the clamped node. For example, in Dutch the activation of SF /s/ could activate, among others, SF /l/, /p/, /i/, /e/, /u/, but not SF /r/, as /sl/, /sp/, /st/, /si/, /se/, and /su/ are all valid phoneme combinations in Dutch, while /sr/ is not. With addition errors, the activity between a clamped node and a connected unclamped node has spread to such an extent that it will result in the unclamped node to be clamped and, subsequently, transfered to the next level(s) of representation, after which it will be included in pronunciation.

4.5.1 Results – patient 1

The first couple of Abstract Neural Networks, that is, figures 4.1 to 4.5 are based on the data set from patient 1. The errors are modeled in order to provide a graphic explanation of what happens at the different levels of representation during the production of phonemic paraphasias. All figures will be followed by a description of the (connections in the) model. An explanation and interpretation thereof will be provided in the discussion section that will follow the current results section.

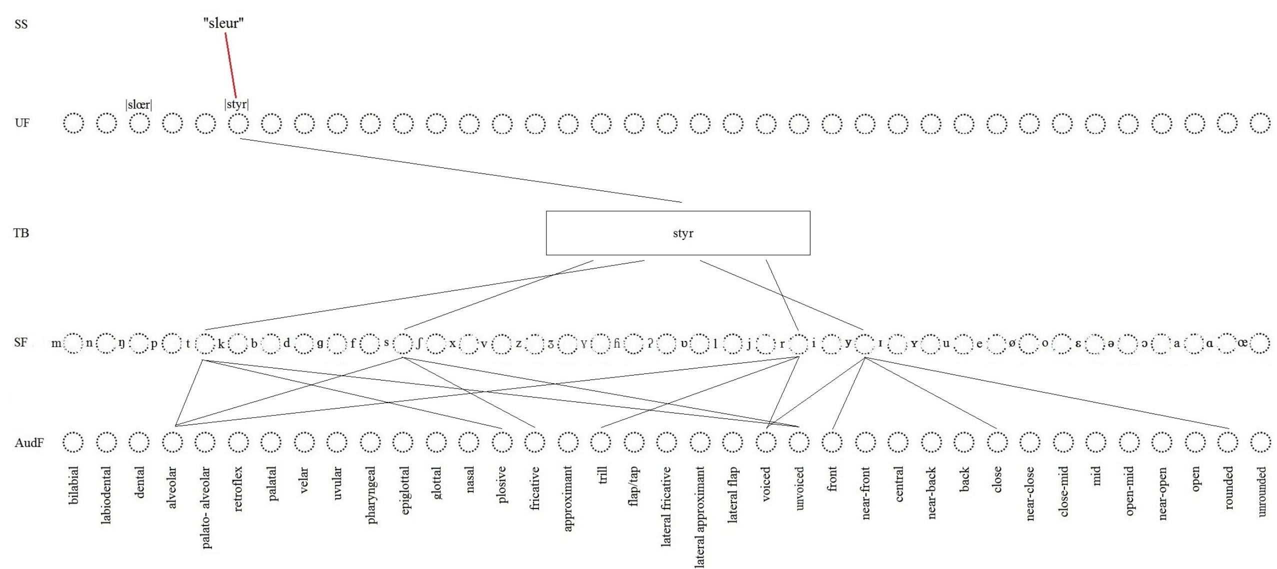
Figure 4.1a shows how the Semantic System concept “sleur”, activates the UF |slœr|, which is subsequently transferred to the Temporal Buffer. The four lines under the TB represent the order, from left to right, of identification in the SF level and AudF level respectively. The most left line activated SF /s/, which subsequently activates the AudF features [alveolar], [fricative], and [unvoiced]. This process is repeated for the SF /l/, /œ/, and /r/, as the second line under the buffer activated the SF /l/, the third line the SF /œ/, and the fourth, and most right, line, SF /r/. However, 'sleur' is not pronounced correctly, since there is a red line between the SF node /œ/ and the AudF

Figure 4.1a Patient 1 – test moment 1 – production of phonemic substitution



node [close]. As argued before, all nodes are between and within levels are fundamentally connected. Originally, /œ/ is connected with strong connection weight to AudF features [front], [open-mid], [rounded], and [voiced], but the weight between /œ/ and [open-mid] has apparently decreased to such an extent that the weight between /œ/ and, originally non-corresponding node, [close] has become stronger than that between /œ/ and [open-mid]. Changing the vowel height from [open-mid] to [close], will cause the SF /œ/ to be pronounced as [y], causing 'sleur' to be pronounced as [sly:r]. The red line thus represents an incorrect activation, which indicates a substitution of a segment feature that changes the original SF segment. In healthy non-brain-damaged individuals, connections between non-corresponding segments surface only rarely, for example, in case of a slip-of-the-tongue.

Figure 4.1b Patient 1 – test moment 1 – production of phonemic substitution



As opposed to the word production error modeled in figure 4.1a, figure 4.1b above shows the modeling of a word selection error. Both error types are produced by the same patient in an effort to produce the original target word 'sleur'.

Figure 4.2 Patient 1 – test moment 1 – production of phonemic addition

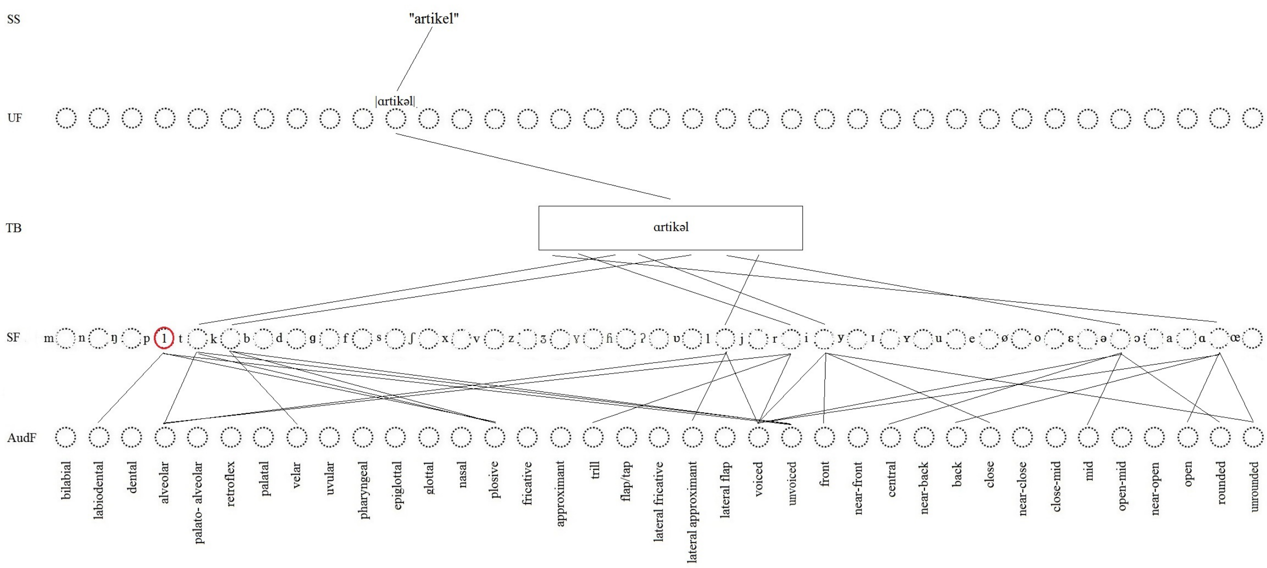


Figure 4.2 above shows a phonemic addition to the word 'artikel' at T1 for patient 1. The model shows how the Semantic concept “artikel” correctly activates UF |ɑrtikəl|, which is subsequently transfered to the TB. The seven line under the TB activate the separate UF segments at the SF level in the correct order, from where their corresponding AudF features are correctly identified and activated. What stands out is the red clamped SF node /p/. The red node indicates an incorrect activation of a SF segment. The number inside the node provides information on the position of the added element in the word; in this case, the SF /p/ is added word-initially.

Figure 4.3a below shows an omission that turned into a word selection error. As the word 'bakker' is an existing word in Dutch, it is assumed here that this is a word selection error. The red line in the model shows the localization of the word selection error, namely between the Semantic System and the UF level, as an incorrect underlying form of the Semantic concept “bakkerij” was selected.

Figure 4.3a Patient 1 – test moment 1 – production of phonemic omission

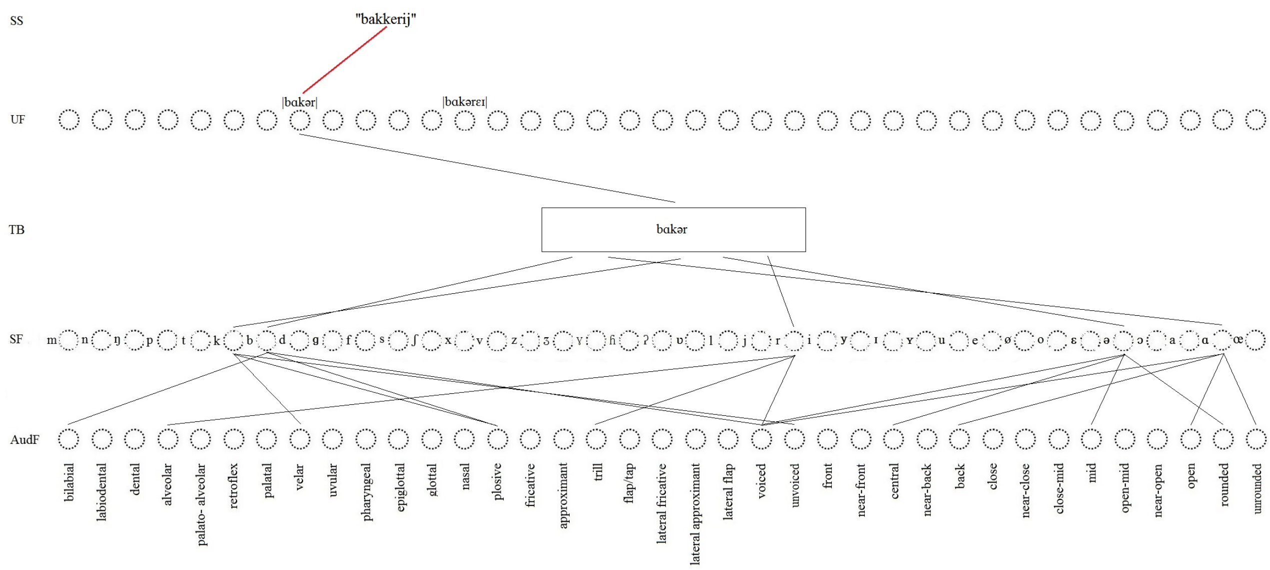


Figure 4.3b Patient 1 – test moment 2 – phonemic omissions

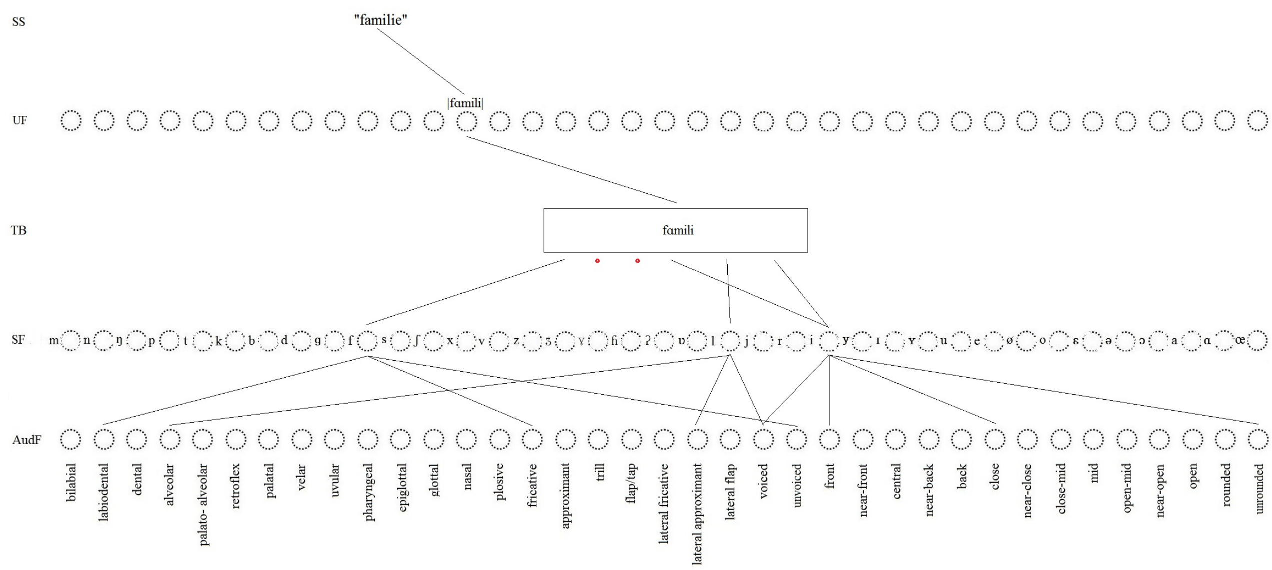


Figure 4.3b above shows a word production omission error at T2. The model shows activation of the correct UF and correct transfer of the UF to the TB. “Familie” has six underlying segments, but as can be seen in the model, only four are transferred to the SF level. The two small red dots under the TB box indicate the missing connections from the buffer to SF /ɑ/ and /m/.

Figure 4.4 Patient 1 – test moment 2 – production of phonemic metathesis

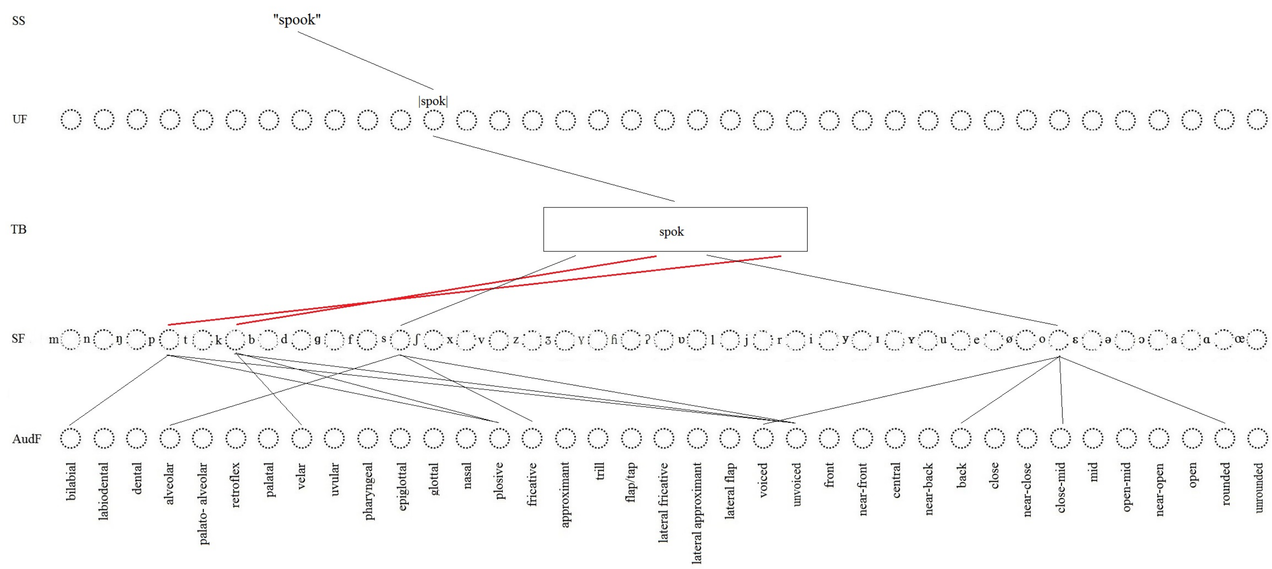


Figure 4.4 above shows a metathetic error in T2 only. Metathetic errors were only made at T2. The model shows, again, correct identification of the UF as well as correct transfer to the buffer box. The red lines between the buffer and the SF level indicate the segments that were not realized in the intended order. The first red line, representing the second segment of the word, connects the 'p' buffer segment with the SF /k/ segment, instead of the SF /p/ segment. The second red line, representing the fourth and final segment of the word, connects the 'k' buffer segment with the SF /p/ segment, instead of the SF /k/ segment.

4.5.1.1 Patient 1 data summary

Figures 4.5a and b below show an overview of all impaired nodes and connections at T1 and T2 respectively. Only impaired nodes and connections are modeled, and all errors in figures 4.5a and b are based on the data overview tables in section 4.4 above. The red lines between the SF and AudF level indicate substitutions, the red clamped nodes at the SF level indicate additions, the red phonemes in the buffer indicate the segments that were omitted. When looking at the nodes and connections involved in the phonemic paraphasias made by patient 1, a first element that stands out is the number of red connections, representing the substitutions, between the SF and AudF level. Although an equal amount of substitutions take place at T1 and T2, more vowel substitution errors are made at T1 than at T2, and more consonant substitutions took place at T2 than at T1. At T1, SF /a/ and /œ/ had more non-corresponding connection to AudF features than all other segments. The vowel substitutions mostly included connections to peripheral AudF features, like [front], [back], and [close]. At T2, SF /i/ and /f/ had more non-corresponding connections to AudF features than all other segments, as did SF /t/, which is also the only segment included in substitution as well as another error type, in this case addition. It may thus be argued that the nodes involved in substitutions operate separately from the other error types. More additions occurred at T1 than at T2, meaning that less segments were additionally activated at T2. More segments were omitted at T2 than at T1, but all segments omitted at T1 were also omitted at T2. This may imply that over the course of seven weeks, the buffer function of keeping segments in memory has decreased. Metathetic errors are not displayed in the Network, but only occur at T2, indicating an additional possible decrease in buffer function, namely that of maintaining the order of incoming segments. At T1, considering all error types, sixteen errors were word selection errors, originating from

Figure 4.5a Patient 1 – data summary – test moment 1

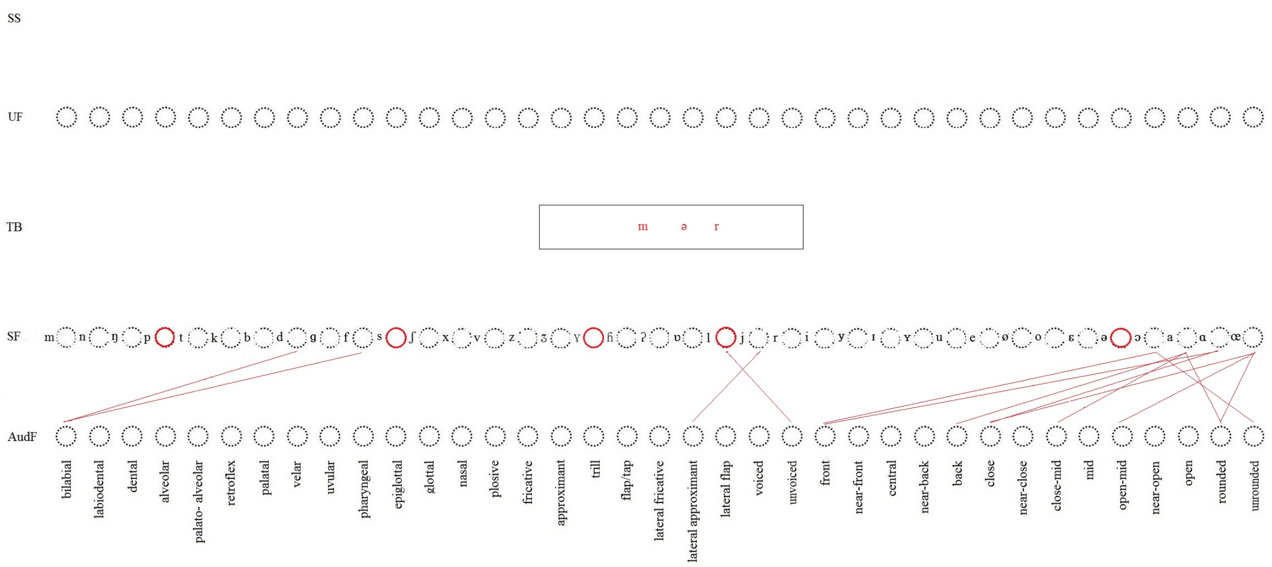
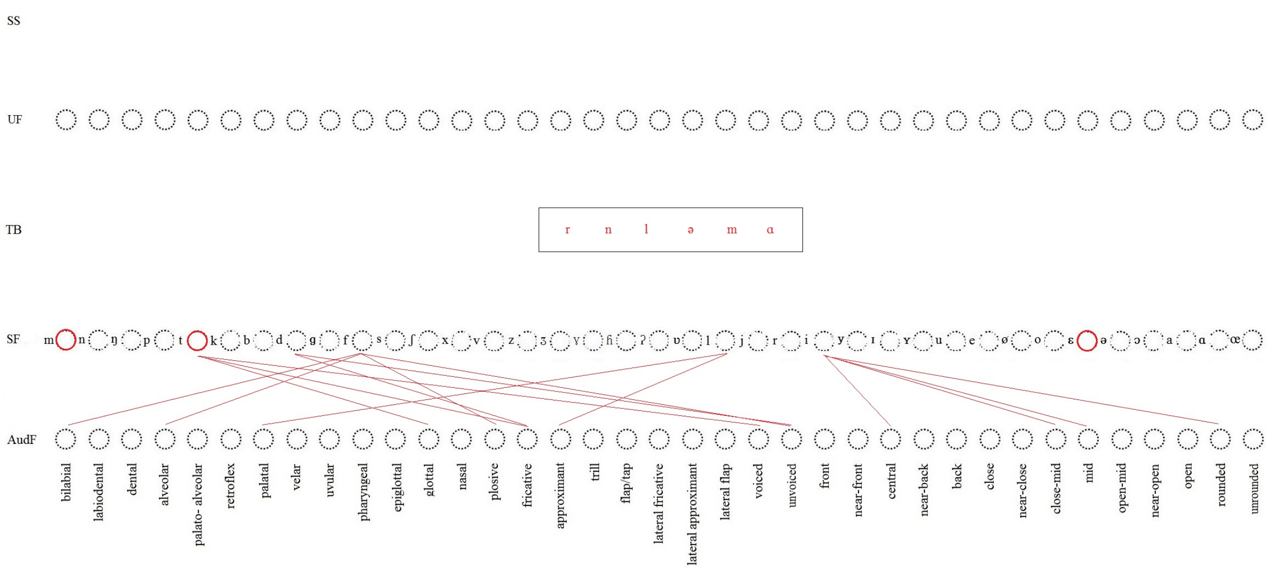


Figure 4.5b Patient 1 – data summary – test moment 2



substitutions and omissions; at T2, a total of six word selection errors occurred, originating from substitution and addition. The total number of word selection errors has thus decreased over the period of seven weeks time. Finally, it might be argued that nodes that are involved in multiple errors types, indicate that those segments are more severely impaired that those involved in only a single error type.

4.5.2 Results – patient 2

The next figures, figures 4.5 to 4.10, are Abstract Neural Networks created with written data from patient 2. Phonemic errors made by patient 2 will not be modeled here, since these errors are modeled in the same way as the phonemic errors made by patient 1. Like the Networks for patient 1, the following Abstract Neural Networks will be described here and explained in the discussion section.

Figure 4.6 Patient 2 – production of graphemic substitutions

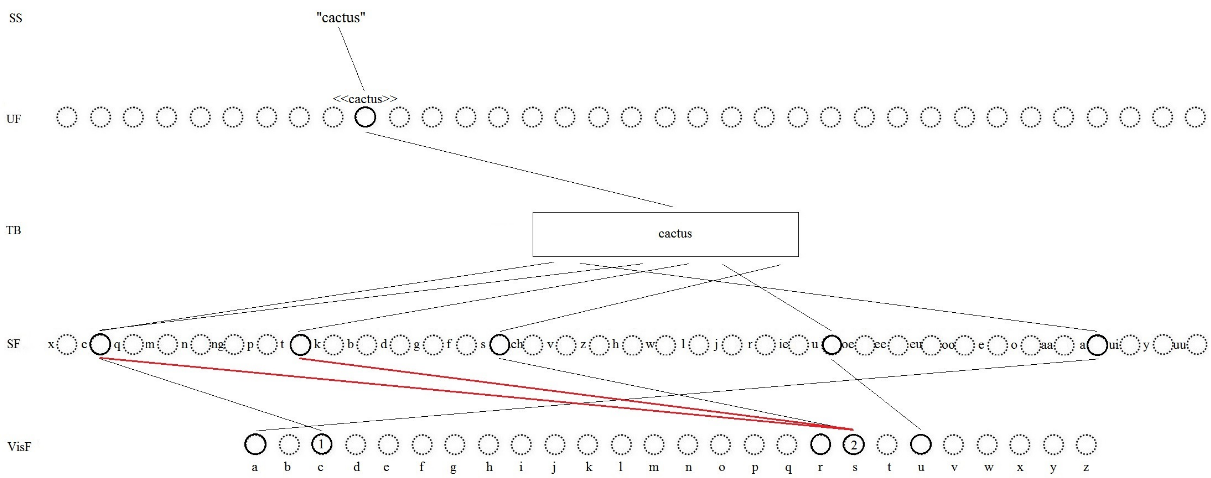


Figure 4.6 above shows a graphemic substitution made by patient 2. First note how the Neural Network for graphemic errors is different from that for phonemic errors. The UF contains graphemic word forms, the SF contains single graphemes that represent phonemes in Dutch, and the VisF consists of the 26 letters that represent the Dutch alphabet. The SF contains more graphemes than there are letters in the alphabet as some letter combinations represent a single phoneme or and some single letters represent two different phonemes, for example, graphemic SF <ch> represents phonemic SF /ʃ/, graphemic SF <a> represents phonemic SF /ɑ/, graphemic SF <aa> represents phonemic SF /a/, graphemic SF <eu> represents either phonemic SF /œ/ or /ø/, and graphemic SF <j> represents either phonemic SF /j/ or /ʒ/.

The model in figure 4.6 above shows how the Semantic concept “cactus” its corresponding UF form are activated, and how the Underlying Form is subsequently transferred to the Temporal Buffer. As in the networks for the phonemic modeling, the lines under the buffer box represent the order, from left to right, in which the single graphemic segments are also correctly identified at the SF level. Going from the SF to the Visual Form level, that is, the actual written form of the word, the model shows that first SF <c>, and then SF <a> are correctly identified as VisF 'c' and VisF 'a' respectively. The two red lines show the substitutions, as the third SF segment <c> and fourth SF segment <t>, do not connect to their corresponding VisF segments 'c' and 't' respectively. They are rather both connected to VisF segment 's'. Finally, the fifth and sixth segment, SF <u> and <s> respectively, are, again, correctly connected to their corresponding VisF segments 'u' and 's'. From the model, the regressive consonant harmony can also be seen, as the two preceding SF segments <c> and <t> are also connected to the VisF 's' of the word-final SF segment <s>. The number '1' in the VisF 'c' segment indicates that the first SF <c> segment activated the VisF 'c', and the number '2' in the VisF 's' segment indicated that the second SF <c> segments activated the VisF 's'.

Figure 4.7 Patient 2 – production of graphemic addition

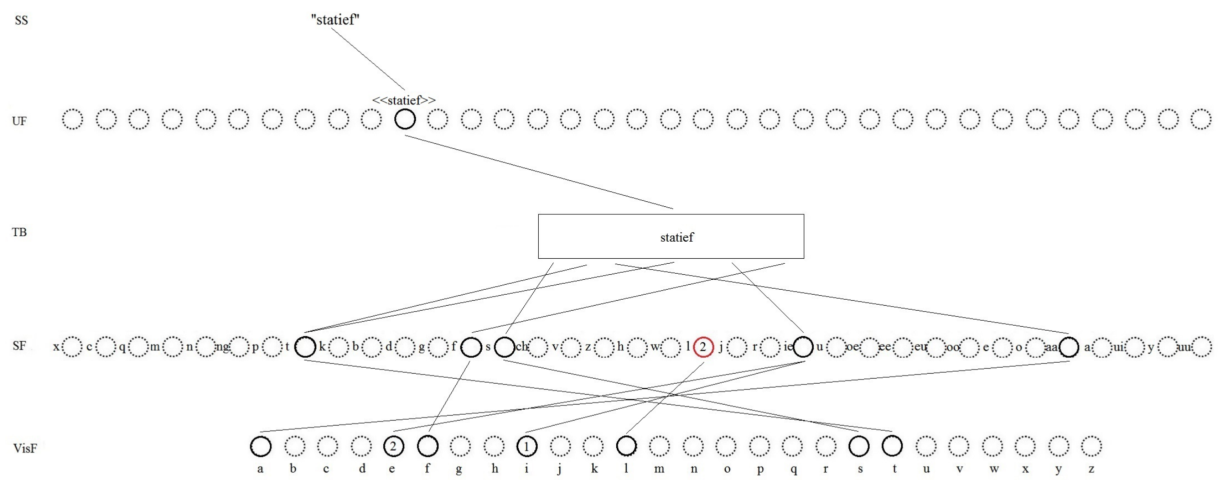


Figure 4.7 above shows a graphemic addition made by patient 2. It shows how the production process is correctly executed up until the Temporal Buffer, including the activation of the correct SF segments. As with the phonemic additions, the SF <s> activated the SF <l> via a within-level connection to such an extent that the SF <l> node became clamped, and subsequently activated the corresponding VisF 'l'. The number '2' in the SF <l> node indicates that the node was activated as the second segment in the word, resulting in the written production of 'sltatief'. Although 'sl' and 'lt' are valid letter combinations in Dutch, 'slt' is not. The activation of SF <l> was apparently so strong that it was activated despite the fact that it violates a phonological consonant combination rule. Note

that the activation of SF <ie> first spreads to VisF 'i' and then to VisF 'e', keeping the order to the original SF segment. Finally, note that the UF <<a>> is connected to the SF <aa>, instead of SF <a>. As graphemes represent phonemes, the UF <<a>> is connected to SF <aa>, because 'statief' is pronounces with a phonemic SF /a/, and not with a phonemic SF /ɑ/.

Figure 4.8 below shows a graphemic omission made by patient 2. It shows an impairment in the buffer function as the fifth and sixth segment are not transferred to the SF level. Although SF <k> is activated twice, there are no numbers in the VisF segment 'k' as the SF <k> was correctly identified as VisF 'k' both times. Note that the segments under the buffer are processes sequentially rather than simultaneously, and that they are only represented in the same network due to limitations of time and space.

Figure 4.8 Patient 2 – production of graphemic omission

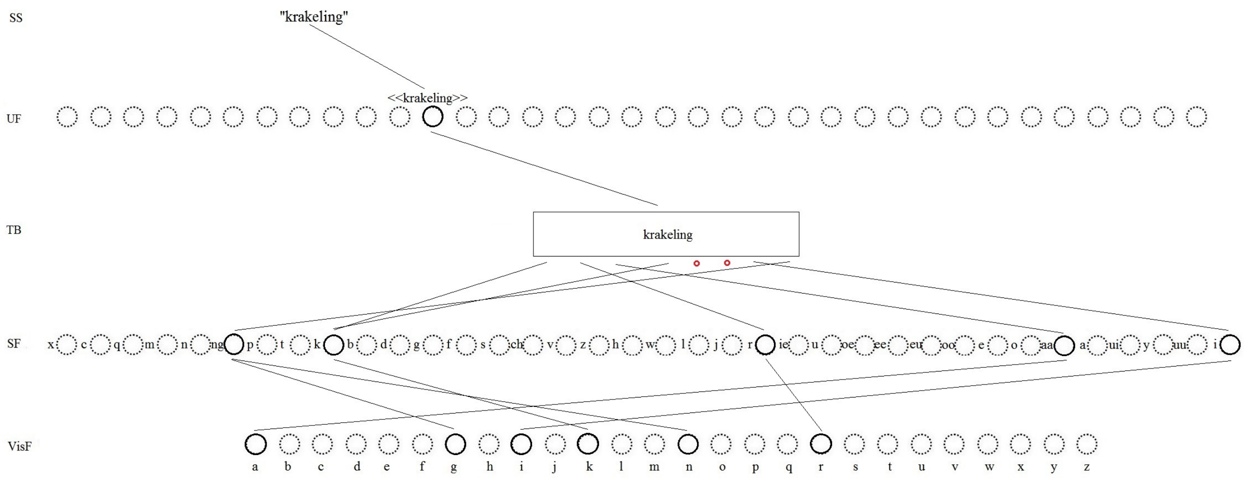


Figure 4.9 Patient 2 – production of graphemic metathesis

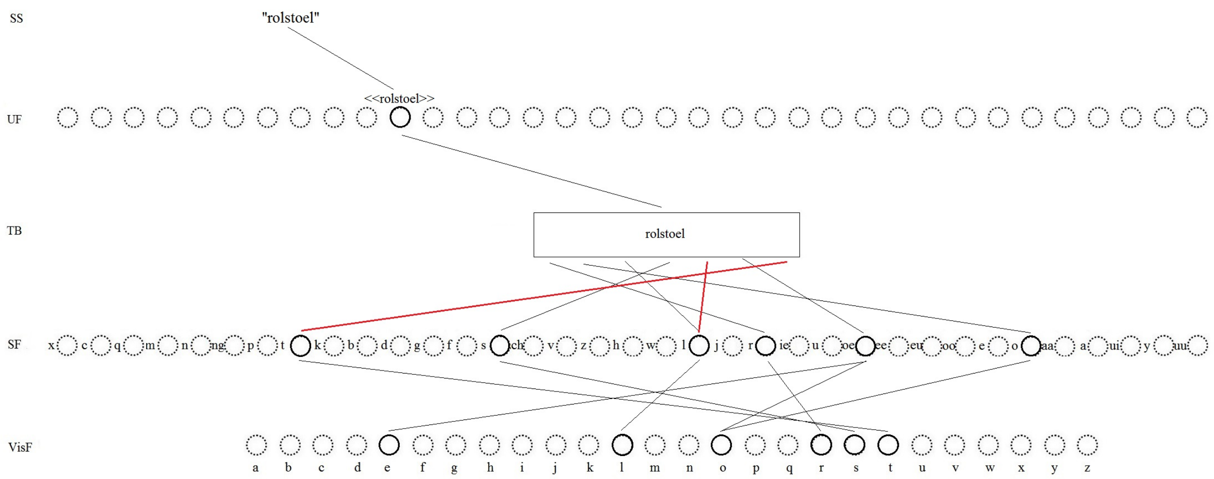


Figure 4.9 above shows a graphemic metathetic errors made by patient 2. It shows the correct identification of the Semantic concept, as well as the subsequent UF activation and transfer to the buffer. Inside the buffer, however, two segments are switched, namely SF <t> and word-final SF <l>, causing the word-final SF <l> to form a cluster with SF <s>, which is allowed in Dutch, and the SF <t> to move to word-final position. From the SF, all segments, including the metathetic ones, are transferred correctly to their corresponding Visual Forms. Note how SF <oe> activates both VisF 'o' and 'e' in that particular order.

4.5.2.1 Patient 2 data summary

When looking at the nodes that are involved in the different error types in the data set of patient 2, a couple of differences between written and verbal production are noticeable. Figure 4.10a and b below contain the impaired nodes and connections involved in the assembled verbal and written production respectively. Only impaired nodes and connections are modeled, and all errors in figures 4.10a and b are based on the data overview tables in section 4.4 above. Firstly, an approximately equal number of substitutions are involved in phonemic and graphemic errors, none of which include vowels. Besides substitutions, only two omission errors, and two word selection errors, originating from substitution errors, occur in the verbal production. All SF nodes involved in substitution, connect to more two non-corresponding AudF nodes. Only SF /l/ is involved in both substitution and omission. The AudF node involved in most substitutions is [unvoiced], meaning that the phonological process of devoicing voiced consonants occurs most often. In total, more graphemic than phonemic errors seem to occur in the data set. In the written production, all four

Figure 4.10a Patient 2 – data summary phonemic errors

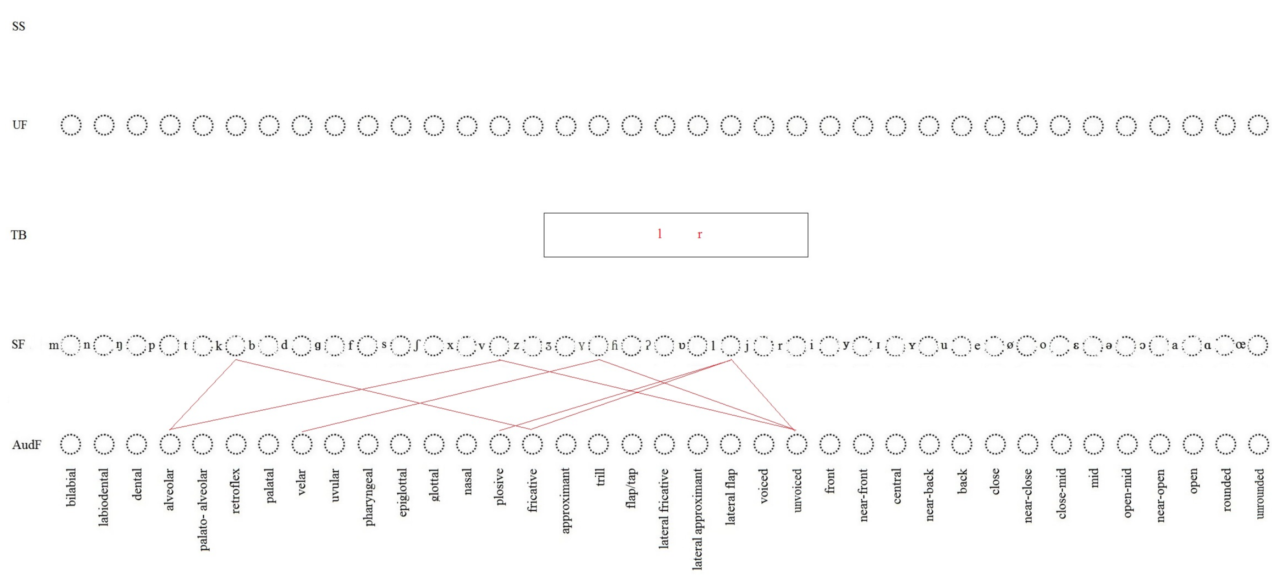
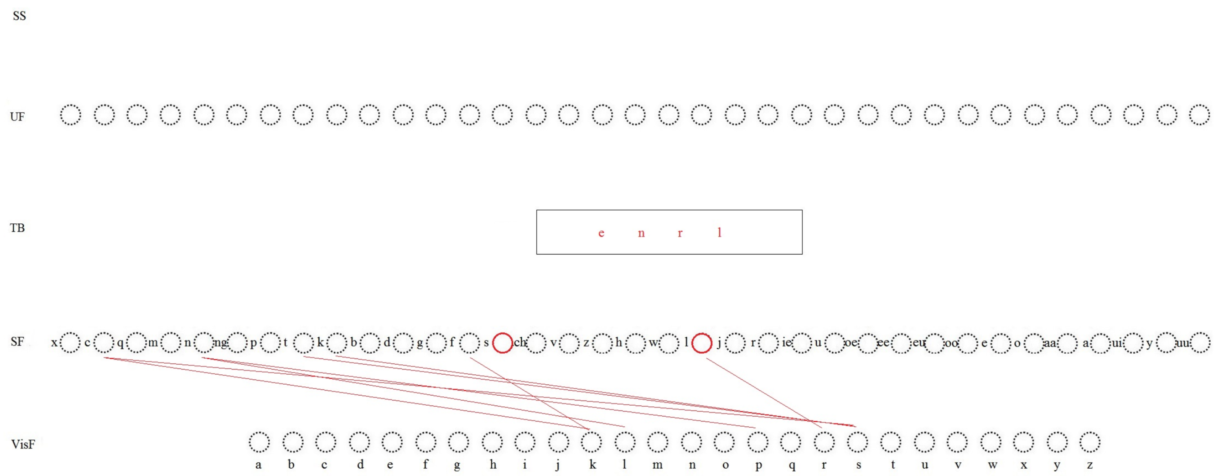


Figure 4.10b Patient 2 – data summary graphemic errors



error types occur more than once. The Network includes two addition errors and four omission errors. Of the four segments involved in omission, the <e> occurs four times, the <n> two times, and <r> and <l> only once. Additionally, but not present in the Network, two metathetic errors and five word selection errors, originating from addition errors, occur in the graphemic data set. Noticeable is the <l> segment that is involved in all four error types. The <n>, <r>, and <k> all occur in two different error types, and VisF 's' is connected to non-corresponding SF segments most often, namely three times.

4.6 Discussion

For patient 1, it can be argued that after seven weeks, there has been a shift in error types. Although there were less additions and vowel substitutions at T2, there were also more omissions, metathetic errors, and consonant substitutions at T2, balancing out the total number of errors made. Most vowel substitutions at T1 connected to more peripheral AudF features than the corresponding AudF features. Although the “production of a more peripheral value requires more articulatory effort”, the connections to the more peripheral values might indicate an unconscious 'need' to produce a “non-confusable token of the category” (Boersma, 2012, p. 28/29). Less word selection errors occurred at T2, compared to T1, which might indicate an improvement of the connections between the Semantic System and the Underlying Form. The error types omission and metathesis both occur at the buffer level. As the nodes and connections seem to have benefited from speech therapy and plasticity of the brain, allowing to rearrange broken connections, the Temporal Buffer does not seem to have benefited from either therapy or plasticity.

For patient 2, it can be concluded that more errors and more error types were made in the written production than in the verbal production. However, one node in particular, namely the SF

<l>, seems to be more impaired in both modalities than all other nodes. Although the lexicons and output routes for verbal and written production seem separate, this implies that they must be connected to a certain extent. Nodes like SF <l> may be argued to be more severely impaired than nodes that are not involved in as many errors and error types or that do not occur in both modularities.

Given that, for both patients, correct transfers between corresponding SF and AudF nodes, resulting in correct production of the target item, have also taken place, it cannot be assumed that the connections between SF segments and their corresponding AudF features are entirely broken; or set back to a weight of zero. It should, furthermore, be noticed that, besides correct target productions, both patients also had items they were unable to produce, even after *conduite d'approche,* that is, successive approximations in order to reach the target item. This may be an indication of how nodes and connection weights that are affected by damage to the language areas of the brain are returned to a 'child' stage, in which experience has to be gained in order to reach stability. In this state of regression, where previously gained experiences and confirmations are, at least partially, reduced or, in some cases, even erased, a patient may thus produce a multitude of errors, as (part of the) the feedback system is no longer operating to its full potential.

Additionally, as touched upon before, the concept of bi-directionality, as proposed by Boersma et al. (2012), can also be called into question, considering the fact that the impaired nodes and connections do not cause similar deficits in comprehension. This was tested during the standard test moments at Rijndam with different comprehension tasks. This may, thus, imply separate networks for production and comprehension, as opposed to modeling both in one and the same network.

On the basis of the data sets of the two patients included in this study, no generalizations can be made as to shifts in connections weight. Meaning that it cannot be stated that, for example, the connection weight between SF /s/ and AudF [fricative] is reduced and the connection between, for example, SF /s/ and AudF [plosive] has increased, since no consistent substitutions, additions, omissions, and/or metatheses have taken place. On the basis of the data set from this study, and considering that two or more individuals with aphasia rarely present with the same linguistic deficits, shifts in connection weight and/or impaired nodes should thus be accounted for and interpreted individually and on a case study basis.

4.6.1 Impaired nodes and connections and Executive Functions

When language skills are impaired, "individuals need to rely on other cognitive skills in order to communicate" (Purdy, 2015, p. 550). Other cognitive functions include, among others, the previously discussed 'working memory' and 'inhibitory control'. Relating these two cognitive functions to the phonemic and graphemic errors made by the patients included in this study, it might be argued that working memory and inhibitory control are involved in all error types, and that all error types include a decrease in inhibitory control. Word selection errors ignore the inhibitory function of choosing an incorrect word form, at the earliest stage in Neural Network processing; followed by additions, omissions, and metathetic errors, which allow incorrect segments to be passed on to the next level of processing. Finally, of the four error types discussed in this paper, substitutions ignore inhibitory control at the latest moment in processing, as they allow activation of incorrect segments to the Auditory Form level. Additionally, omission and metathetic errors also show insufficient operation of working memory as, with omissions, not all segments of a word form are transferred to the SF level, and as, with metathesis, not all segments are transferred in the correct order. Impaired inhibitory control and insufficient operation of working memory may thus also play an important role in phonemic and graphemic errors made by patients with aphasia.

4.7 Summary

In this chapter an overview was provided of the patients, materials, procedures, and data. The data was analyzed and Abstract Neural Networks were provided and discussed. The data sets of both patients were elaborated on separately, and conclusions as to the separate data sets were drawn. The next chapter includes a general conclusion of this study.

5. Conclusion

In this final chapter, the present study and its main findings will be evaluated. Additionally, limitations will be discussed as well as future possible studies and possible clinical applications. This paper modeled the development of phonemic paraphasias from one patient, and the difference between phonemic paraphasias and paragraphias from another patient. All errors were modeled with an Abstract Neural Network, a type of neural network specifically adjusted for the present study. The levels of representation for verbal processing were based on those used in the Neural Network as proposed by Boersma et al. (2012), and the levels of representation for written processing were based on written language processing elements from the PALPA language processing model. An addition level, with a temporal buffer function, was proposed in order to be able to include and model a memory function. Four error types were looked into, namely: substitutions, additions, omissions, and metathesis. Substitutions were localized between the buffer and the Surface Form level. Additions were localized at the buffer level where additional nodes were activated during the activation of an Underlying word Form. Omissions and metathetic errors were also localized at the buffer level, more specifically, at the memory function and maintaining the order of segments, respectively.

It was expected that, for patient 1, less errors would occur at test moment 2 than at test moment 1. However, this proved not to be the case. Indeed, less substitutions and additions occurred at T2, but more omissions and metatheses also occurred at the same test moment, balancing out the total number of errors. As omissions and metatheses originate from impairments to the memory buffer function, the patient's cognitive functioning should also be considered when analyzing these error types. For patient 2, it was expected that the impaired verbal and written nodes and connections were not related. Although not enough evidence was found to support this hypothesis, some nodes were, in fact, impaired in both modalities, hinting at the possibility of a connection between the different levels from the verbal and written output routes.

Finally, the Neural Network modeling done in this study, calls into question the proposed bi-directionality by Boersma et al. (2012). The modeling shows how, for the two patients included in this study, top-down production processing is selectively impaired, while bottom-up phonological comprehension processing has proven to be intact by means of different (phonological) comprehension tasks.

5.1 Limitations

Since no two individuals with aphasia present with the exact same clinical image, it is difficult to make generalizations, regardless of the set-up of the present study. Due to limitations of time, I had to work with existing language tests, therefore, I was unable to control for the segments used and the number of segments and words tested. Finally, the Abstract Neural Network used for this study was designed specifically to restrict the modeling to a general overview of impaired nodes and connections. Thus, it did not show more detailed changes in connection weights, which might be considered as a general deficiency of the network.

5.2 Possible future studies

On the basis of the limitations discussed above, a number of improvements can be proposed for future research into this topic. First, I would like to argue that it might be convenient to design a test that will allow for a more detailed and specific analysis of the nodes and connections. It is important that the test contains all possible segments used in Dutch, preferably multiple times, in order to be able to evaluate the connections. Second, if time allows, it would be interesting to test multiple patients and model their errors. Finally, a template for an operable Neural Network should be designed, which allows for the evaluation of more exact connection weights. Additionally, a learning algorithm should also be included in order to be able to predict improvements of the impaired nodes and connections.

5.3 Clinical application

As for the clinical application of a Neural Network with the proposed improvements from section 5.2, I would like to argue that this model, including the proposed test, will be a good instrument for mapping out phonological impairments in individuals with aphasia. Currently, in the clinical practice, phonological impairments are noticed, but not dealt with separately in therapy. Phonology is combined with semantic therapy, primarily in comprehension, with, for example, verbal or written semantic comprehension exercises including phonological distractor pictures or words. However, insight into impaired connections between levels could be gained, if I could design a test and a digital Neural Network to evaluate the test outcomes with. On the basis of these insights, a more 'connection-directed' therapy can be provided for aphasics with phonological impairments, which will allow for specific repairing or rearranging of connections.

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