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Sentence Processing in Agrammatic Aphasia

Master thesis

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I hereby declare that I have completed this thesis including its appendices on my own and used solely the sources cited in the text and included in the bibliography.

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Acknowledgement

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Introduction

Agrammatic aphasia, also known as *agrammatism,* is a speech disorder caused by damage to brain areas involved in grammatical aspects of language. It is characterized by specific lexical, morphological and syntactic disruptions affecting both production and comprehension modalities. Theoretical debates on agrammatism cluster around one central question: *What types of impaired operations and/or processes underlie the disruption of grammatical abilities in agrammatic aphasia?* This thesis focuses on the theoretical and experimental approaches to this question developed over the past three decades within the field of linguistic aphasiology. Special attention is given to comprehension deficits and their underlying causes. However, the production deficits will also be discussed, as to provide the reader with a broader picture of agrammatic aphasia. Additionally, this thesis will build upon research on comprehension and production deficits to provide a more specific discussion of asyntactic comprehension patterns and to report an experiment investigating this asyntactic comprehension in Czech agrammatic speakers.

The thesis attempts: 1) to introduce the syndrome of agrammatism and different theoretical perspectives on this syndrome; 2) to discuss its specific symptoms in more linguistic detail; 3) to describe the most common methods and experimental approaches that have been used in the research of agrammatism; 4) to review theories of comprehension deficits in agrammatism and to critically evaluate them; and finally, 5) to report an experiment studying comprehension in Czech agrammatic aphasics and healthy controls, and to discuss its implications and contributions to the research of agrammatism. Thus, the thesis is divided into two main parts: I) The Theoretical Part and II) The Experimental Part. The Theoretical Part is further divided into four Chapters:

Chapter 1 introduces and demarcates the syndrome of agrammatism, as well as the field of linguistic aphasiology.

Chapter 2 describes the symptoms that arise in agrammatism, and their manifestation across different languages, including Czech.

Chapter 3 introduces different methods and paradigms that have been applied in the experimental research investigating agrammatism; discusses how these approaches

address distinct types of hypothetical questions; and critically evaluates them.

Chapter 4 provides a review of different theoretical approaches to comprehension deficits in aphasia; and provides a current overview of the empirical studies that are in support of these theories.

The Experimental Part consists of Chapter 5, that builds upon the theoretical background presented in the Theoretical Part of the thesis and aims to test selected hypotheses on comprehension deficits in agrammatism by investigating comprehension of active and passive sentences in Czech agrammatic participants and healthy controls This investigation attempts to explore the underlying nature of comprehension deficits in agrammatic aphasia in Czech.

I.

The Theoretical Part

1. Introduction to agrammatic aphasia

1.1. What is agrammatism?

This introductory chapter aims to provide the definition of agrammatic aphasia, and to inform the reader about some central issues on research in agrammatism (e.g., individual and cross-linguistic variation). It further discusses problems regarding clinical classification, and provides information on anatomical correlates of agrammatism. Finally, it gives an overview of different approaches to the study of agrammatism (e.g., linguistic aphasiology, clinical aphasiology and neurolinguistics), and argues the importance of research on the agrammatic syndrome.

1.1.1. Definition of agrammatism

Agrammatic aphasia, also referred to as *agrammatism*, is a language disorder resulting from damage (e.g., stroke or trauma) to the brain areas responsible for language processing. Agrammatism is characterized by non-fluent speech production with grammatically impoverished sentences in which syntactic and morphological devices are limited (Goodglass & Menn, 1985). Although disrupted speech production is the most prominent characteristic of agrammatism, the modern definitions acknowledge asyntactic comprehension as another common feature of agrammatic aphasia (Zurif & Caramazza, 1976; Thompson & Bastiaanse, 2012). Moreover, the deficit can be observed in both reading and/or writing modalities (for more details on agrammatic symptoms in distinct modalities see Chapter 2).

Notably, not all the aspects of agrammatism mentioned above are always present in all agrammatic individuals. Some may have production difficulties but comparatively preserved comprehension, while others may experience more difficulties in production of inflection forms. Despite the inherent variability across individuals, which may be caused by a variety of factors (e.g., different severity of impairment or differential disruption of the processing components of language), two main features are accepted as universal symptoms of agrammatism: 1) *difficulties in functional elements* and 2) *simplified syntactic structures* (De Bleser, Burchert, Holzinger, & Weldich 2012, p. 122); in order to be classified as agrammatic, a patient must exhibit these central symptoms.

Moreover, cross-linguistic studies on agrammatism show that some deficits associated with agrammatism can be absent or manifested to a different degree from one language to another. In fact, differences in languages account for even more variance than differences across individuals within the same language (Bates, Wulfeck, & MacWhinney, 1991). Therefore, as Menn and Obler (1990, p. 3) argue, cross-linguistic studies are increasingly important, and plausible theories of agrammatism must be framed in a fashion that is independent of the specific morphological and syntactic devices that any particular language may use (for more information on cross-linguistic differences in agrammatism see Chapter 2).

1.1.2. *Language loss and recovery in agrammatism*

The agrammatic symptoms described above are not in a fixed state after the brain damage; the intact processes are gradually reorganized, followed by the spontaneous recovery of impaired functions (Harley, 2014, p. 19). Thus, aphasic performance is not simply the result of language loss – that would be a rather simplified view.

Thanks to the brain's capacity to employ different neuronal structures to re-establish and regain the functions that have been disrupted by damage, spontaneous recovery starts to take place soon after the initial damage. Within only a few months post onset, once lost language functions are newly reestablished, yet in a newly reorganized manner. Due to the damage in language related areas, the language functions are executed by altered neuronal networks. These neuronal networks may not have been originally dedicated to language processes. Thus, function is executed differently after recovery. The speaker has to adapt to these vast differences by using specific compensatory strategies to deal with the linguistic tasks that are now being executed in a slightly different fashion. Caplan and colleagues describes the aphasic behavior as follows: "Aphasic performance can be characterized as the result of normal functions, minus functional deficits, plus compensations" (Caplan, Waters, Dede, Michaud, & Reddy, 2004, p. 64).

But despite the differences between normal language processing and aphasic speech, it is still very useful to study how aphasic language relates to normal language processes, as such comparisons can help us to understand the nature of impairments, and to inform models of normal language processing.

1.1.3. Agrammatism and Broca's aphasia

Agrammatism is often associated with Broca's aphasia, a syndrome named after the French surgeon Paul Broca (1824–1880), who first described the language impairment resulting from brain damage in the inferior frontal gyrus, namely in *pars opercularis* and *pars triangularis* (e.g., Brodmann's areas 44 and 45).[1] However, Broca originally associated these discovered areas with the loss of articulatory abilities, rather than with specific grammatical impairments. The impaired faculty of articulations that Broca had observed (Tesak & Code, 2008, pp. 47-51), would in a modern clinical definition be referred to as apraxia of speech, which is now considered to be only one of the symptoms of Broca's aphasia (Bastianse & Thompson, 2012, pp. 4-5). In fact, there are often overlaps of agrammatism and apraxia, and pure agrammatism without any motor planning deficit is associated with less severe brain damage.

Modern definitions of Broca's aphasia merge both articulatory and grammatical impairments with other symptoms together under one overarching diagnosis. For example, Goodglass and colleagues define Broca's aphasia as "awkward articulation, limited vocabulary, restricted grammar, to the simplest and most overlearned forms, with deletion of obligatory grammatical words (…) and auditory comprehension (...) relatively preserved" (Goodglass, Kaplan & Barresi, 2001, p. 61). The combination of deficits in Broca's aphasia and their severity varies from patient to patient. Thus, not all the Broca's aphasics can be classified as agrammatic. Even though it was previously thought (following the findings of Zurif & Caramazza, 1976) that the impaired grammatical representations and the impaired ability to process grammatical structure are common in both Broca's aphasia and agrammatism, this interpretation has been challenged by Linebarger, Schwartz & Saffran (1983), who studied grammaticality judgment in agrammatic aphasia. They found that while patients with Broca's aphasia performed poorly on comprehension tasks relying on syntax (i.e., grammatical representation), they performed well on grammaticality judgment tasks (i.e., processing grammatical structure). Such individuals would not be considered strictly agrammatic, because agrammatic speakers perform poorly on both comprehension and grammatical judgement tasks. In other words, Broca's patients can perform well on grammaticality

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[1] Brodmann's map of the human brain (Brodmann, 1909) is the most widely known and frequently used cyto-architectural organization of the human cortex, that has been renamed and refined exhaustively in the past years to capture the new findings and observations in neuroanatomy of the human brain (see Garey, 2006).

judgement tasks as opposed to agrammatic patients who do not; and this dissociation has been observed cross-linguistically (e.g., Wulfeck & Bates, 1991; Lu et al., 2000; Wilson & Saygin, 2004). Thus, agrammatism and Broca's aphasia may not stem from the exact same neurological impairment.

Furthermore, stroke induced Broca's aphasia is not the only cause of agrammatism. It often appears in neurodegenerative diseases such as Alzheimer's disease (e.g., Kim & Thompson, 2004) or primary progressive aphasia (Thompson & Mack, 2014), but can be induced by tumors, brain trauma, or encephalitis. De Bleser and colleagues argue that agrammatism cannot be associated exclusively with Broca´s aphasia: "There is a tendency for agrammatism to occur within the context of Broca's aphasia. However, there are also cases of Broca's aphasia without agrammatism (…), and of agrammatism without Broca's aphasia" (De Bleser et al., 2012, p. 121).

With the rise of linguistic aphasiology, which introduced more detailed and complex descriptions of the language impairments associated with Broca's aphasia, the term *agrammatic aphasia* has been applied to specific types of language impairments related to agrammatic behavior. The classical clinical taxonomy that simply groups patients under Broca's and Wernicke's aphasia is, as Caplan argues, insufficient in grasping the specific impairments related to agrammatism that occur in these patients:

> All we can say about a patient who has Broca's aphasia is that he has one or more of a number of abnormalities in speech and possibly other functions such as reading aloud, repetition, and writing. This is not enough to be able to say exactly what linguistic and psycholinguistic problems the patient shows in detail. (Caplan, 1987, p. 150).

Applying classical clinical categories can help us to see the problem as a whole but at the same time it is moving us away from identifying the specific sources of the grammatical deficits underlying the morphological, lexical and agrammatic patterns observed in agrammatic aphasia. The impairment can be understood and possibly improved only if detected and carefully described. Therefore, this thesis is concerned with a detailed description of specific types of grammatical impairments that can be investigated, understood and hopefully treated, rather than with the holistic clinical diagnosis. Hence, I am going to use the term agrammatism as a syndrome in its own right throughout.

1.1.4. Neural damage in agrammatic aphasia

In the previous section I argued that even though agrammatism is often associated with Broca's aphasia, the two should be considered as separate syndromes. This is a clear answer to a conceptual issue, but what about the anatomical correlates of agrammatism? To what extent do lesions found in individuals suffering from agrammatism overlap with Broca's area (i.e., the Brodmann's areas 44 and 45)?

Kertesz and colleagues performed a radionuclide scanning to localize lesions of different types of aphasics (Kertesz, Lesk, & McCabe, 1977). The picture below (see Fig. 1.1) represents the composite lesions of 14 participants diagnosed with Broca's aphasia. The composition lesion showed the highest overlap in the left *inferior frontal gyrus* of the frontal lobe (i.e., precisely the Brodmann's areas 44 and 45).

Neurolinguistic studies comparing lesions in agrammatic aphasics often report the frontal regions, but lesions in the regions that extend into *posterior* areas are not uncommon in agrammatic aphasia either. For example, Bonakdarpour and colleagues tried to quantify topographic and volumetric aspects of lesions in agrammatic aphasic patients (Bonakdarpour, Lukic, Garibaldi, den Ouden & Thompson, 2008). They obtained anatomical scans with the use of magnetic resonance from 14 agrammatic aphasics that were diagnosed with agrammatism using *Western Aphasia Battery* (WAB-R; Kertesz, 2007) and specific linguistic testing such as noun naming, production of morphology, canonical and non-canonical sentence comprehension and production. The composite lesion map revealed the biggest overlap in the *perisylvian area,* including the *superior temporal gyrus* (STG) and *the supra-marginal gyrus* (SMG) of the *inferior parietal lobule* (i.e., Brodmann's areas 44, 45, 22 and 40) (see Fig. 1.2). These areas are involved in some, but not all of the individuals diagnosed with Broca's aphasia (Thompson & Bastiaanse, 2012, pp. 8-10).

Fig.1.1. Composite lesions from 14 cases of Broca's aphasia; the darker areas indicate higher lesion overlap (from Kertesz et al., 1977, p. 549).
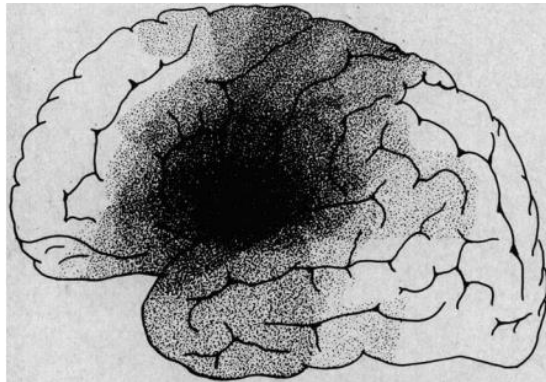
Fig.1.2. Composite lesions from 14 agrammatic aphasics; maximum overlap in light grey, no overlap in dark grey (from Bonakdarpour et al., 2008).
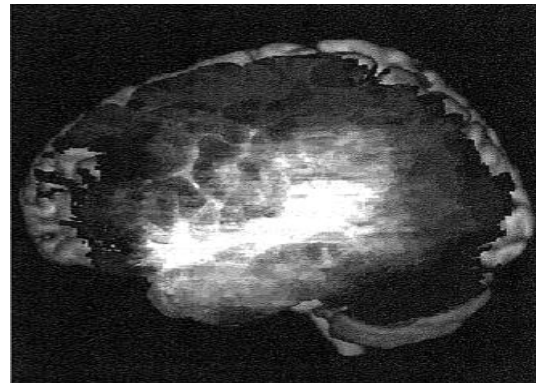
These anatomical correlates of agrammatism are consistent with the findings that not all the patients clinically defined as Broca's aphasics necessarily suffer from agrammatic aphasia, and vice versa. Moreover, the projections from *inferior frontal gyrus* to the *superior temporal gyrus* impaired in agrammatism are assumed to support the information flow related to grammatical processing (see Friederici, 2012).

1.2. Approaches to agrammatic aphasia

This thesis attempts to approach agrammatic aphasia and its related comprehension deficits primarily from the perspective of *linguistic aphasiology*. Therefore, in this section, I would like to explain what is *linguistic aphasiology* and how it relates to *neurolinguistics*, *psycholinguistics* or *clinical aphasiology*. Furthermore, there has been a debate within the field of aphasiology about whether the studies in aphasia should be focused on detailed descriptions of single-cases or rather, to concentrate on group comparisons. This section aims to address both of these approaches, and their related benefits and drawbacks.

1.2.1. What is linguistic aphasiology

Linguistic aphasiology investigates language deficits by implementing detailed linguistic descriptions to theoretically grasp the language structures that have been impaired in patients with aphasia (Caplan, 1987, p. 143). In contrast to *neurolinguistics*,

linguistic aphasiology is not primarily concerned with the neurological basis of these processes. Nor is it trying to relate these impairments directly to normal language processing, which is the subject of *psycholinguistics*; it would not be plausible to consider the full range of language and related cognitive processes that are utilized in unimpaired language users to describe language deficits in aphasia. Impaired language processing employs strategies and adaptations to cope with the deficits induced by brain damage and these strategies are different from the language behavior that we observe in healthy populations. C*linical aphasiology*, compared to linguistic aphasiology, is more concerned with the clinical classification of different aphasic syndromes and their anatomical basis. Finally, the related field of *speech and language therapy*, focuses on the patterns of recovery and treatment of these language impairments observed in different types of aphasia. Thus, linguistic aphasiology constitutes a field of its own as it attempts to describe the language abnormalities observed in specific symptoms of aphasia in more linguistic detail. Such descriptions of aphasic abnormalities contribute to our understanding of how language is represented in our mind, and how one can lose and regain certain aspects of language ability (Caplan, 1987, pp. 143-157).

However, most of the topics linguistic aphasiology focuses on would not have emerged without the preceding clinical and neurolinguistic research, nor without the cognitive models of normal language processing developed within the field of psycholinguistics. What we know about the brain and how it processes language under normal circumstances is informative to our understanding of language processing in aphasia. Conversely, the findings in linguistic aphasiology can inform the psycho-linguistic models of normal language processing and bring valuable evidence to neurolinguistics and clinical research. In this sense, linguistic aphasiology is not an isolated, but rather an interdisciplinary field that contributes to our understanding of aphasic impairments and their relationship to normal language processes (Caplan, 1987, pp. 328-343).

Ideally, linguistic aphasiology, neurolinguistics, clinical aphasiology and speech therapy should all cooperate together and find ways to enrich each other and to mutually contribute to one another. Basic research that is mostly carried on within the field of linguistic aphasiology and neurolinguistics should be linked to and applied in the more practical fields – to clinical aphasiology and speech therapy. Unfortunately, clinical and theoretical research are often working separately. This may be because many researchers get discouraged from interacting with related fields; clinicians find the

linguistic terminology inaccessible and experimental research not important for their everyday praxis, while linguists may have problems understanding the technical vocabulary related to brain anatomy and/or to the diagnostic and therapeutic praxis in general. One solution to this problem might be new interdisciplinary Master and Doctoral programs that would equip future research workers and clinicians with the basic skills allowing these researchers to orient themselves in both of these fields and to pursue interdisciplinary cooperation.

1.2.2. *Case vs. group studies*

Within the field of aphasiology, there has been heated controversy about whether to focus on individual patients (i.e. single-case studies) or rather on group comparison. This controversy arose as the consequence of high variability among individuals with agrammatism. Hence, some authors prefer the single-case studies that, according to their view, are better suited to capture these individual deficits and to better show their underlying causes. For example, Caramazza argues that "only the single-case method allows valid inferences about the structure of cognitive systems from the analysis of impaired performance" (Caramazza, 1986, p. 41). The main argument favoring the single-case studies is that they focus more on the detailed description of individual's language disruptions and on the explanation of these patterns rather than on group comparison of more individuals that can be misleading due to high variability within the group.

On the other hand, those favoring group studies (e.g., Grodzinsky, Piñango, Zurif, & Drai, 1999) argue that single-case studies do not provide researchers with general patterns of agrammatism found across individuals, and thus cannot provide information appropriate for understanding the nature of the deficits. They further argue that "the group studies are not just a valid option in neuropsychology, they are a must" (Grodzinsky et al., 1999, pp. 134-135), as they are more representative of general population trends. While a broader sample gives a more accurate picture of the deficit "the findings from any one patient, without the context of a group, may give a distorted picture of the pathological reality" (Grodzinsky et al., 1999, p. 135).

The disadvantage of group studies is that they are drawing general conclusions based on comparisons among a relatively small group of aphasics with distinct underlying deficits. The group studies focusing on aphasics' speech syndromes usually

do not consist of more than 40 participants as large sample sizes on any specific population are always difficult to obtain. It is not an exception to find studies on agrammatism with 5-10 patients only. One advantage of small group studies may be that it allows researchers to pay attention not only to the group comparison, but also to the individual patterns of impairment found within the group. By these means, the controversy among case-study and group study proponents can be partially resolved.

1.3.   Why study agrammatism?

Arnold Pick (1851–1924) is considered to be the first to systematically study agrammatism (Stark & Dressler, 1990, p. 281). The below quoted passage from *Die agrammatische Sprachstörung* shows his profound interest in agrammatic aphasia, which served as the starting point of agrammatic symptomatology:

> [It must be stated] that agrammatism does not represent just a mere "peculiarity" in the area of aphasiology; on the contrary, it will become evident that the process of the grammatical-syntactic formulations, which is basic to the disorder(s) of agrammatism, forms the bridge, or more specifically, forms a very particular part of a bridge between psychic conception and linguistic alienation of speech. Hence, agrammatism becomes, as it were, the center of aphasiology. (Pick, 1913, p. 16).[2]

The study of agrammatism both theoretically and clinically is still as relevant today as it was a hundred years ago. Studying patterns of agrammatic impairments and their underlying causes can contribute to models of normal language processing and provide novel perspectives on the organization of the language system in the brain. It throws light on the nature of elements within distinct levels of language representation (i.e., phonology, morphology, and syntax), as well as on their interaction (Menn & Obler, 1990, p. 4). For example, if we find preserved phonology but impaired morphology in one individual, but the opposite pattern in another individual, such a finding would

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[2] Translated from German by Stark & Dressler (1990, p. 281).

support the view that the two linguistic levels are separable, and the elements of these levels can be processed even in isolation. This further forces linguistic theories to work with these grammatical levels and elements separately. Contrarily, if such dissociation among grammatical units or levels is not found, there is no neurological justification for treating them as separate grammatical categories/levels.

As Menn and Obler argue, the cross-linguistic research of agrammatism enables us to distinguish between superficial generalizations that only apply within the scope of one language and well-founded generalizations that are language universal. For example, if a theory aims to explain some agrammatic impairment, and operates with a fixed word order that is, however, present only in some languages but not in others, it cannot be said to be universal, and therefore it might not be addressing the real cause of the impairment. On the other hand, finding certain disrupted functions across different languages gives us powerful evidence that there are brain regions that convey these functions. In other cases, data may be ambiguous in one language due to some language specific features (e.g., limited inflectional morphology in English) that do not allow this type of impairment to be clearly manifested (Menn & Obler, 1990, pp. 8-9). However, data from other languages, where such features are richly used, may show the nature of impaired inflectional morphology in more detail. This contributes to a fuller description of agrammatic symptoms, and to the understanding of how they arise from brain damage to specific brain regions. As Thompson and Bastiaanse put it: "without cross-linguistic evidence, any conclusions drawn will be incomplete" (Thompson & Bastiaanse, 2012, p. 13).

The lesion studies (some of which were introduced in section 1.1.4.), that attempt to correlate selected impaired functions with damaged areas, contribute to our language-brain models (e.g., Friederici, 2012). If we are able to define the impairments and associate them with the brain networks responsible for conveying these functions, we may be able to predict under which conditions specific types of agrammatism will or will not occur. The more we know about brain structures and how they process particular tasks, the better we will be able to manipulate these structures. Detailed mapping of very specific linguistic functions onto brain structures and mechanisms will allow us to develop better treatment strategies and even apply the treatment techniques that can enhance one's disrupted functions (e.g., the TMS method discussed in the Chapter 3).

The development of effective treatment approaches to aphasia and its syndromes is increasingly important because the occurrence of stroke induced aphasia is expected to rise in the upcoming years partially also due to the slow aging of the population in the developed countries. According to the statistics, the Czech Republic is among the countries with the highest incidence of stroke in the population above the age of 45 (Truelsen, Piechowski-Jóźwiak, Bonita, Mathers, Bogousslavsky, & Boysen, 2006). Some studies estimate that around 30-55% of stroke survivors suffer from aphasia. Furthermore, agrammatic aphasia often related to the damage of Broca's area and the neighboring brain regions is considered to be the second most common right after the Global aphasia (Scarpa, Colombo, Sorgato, & De Renzi, 1987; Vidović, Sinanović, Sabaskić, Haticić, & Brkić, 2011). The incidence of aphasia is approximated to 1 case on every 250 people which makes this syndrome more common than Parkinson's disease or muscular dystrophy (Aphasia FAQs, 2016). Considering the rising incidence of aphasia and taking into account that the essential role of language abilities in patients' social and working life, the research in agrammatism and its treatment is a must.

2. Production and comprehension impairment in agrammatism

The following section aims to describe agrammatic deficits related to distinct language modalities. The oral production modality, writing, and reading deficits will be introduced to offer a broader picture of agrammatism and of the grammatical impairments which can be manifested in agrammatism. However, this chapter will mainly focus on defining the comprehension modality, as this modality is a central tenet of the Experimental Part. The cross-linguistic differences of the discussed symptoms will be addressed to specify the characteristics of agrammatism for distinct languages. The last section of this chapter is devoted to the characteristics of Czech agrammatism.

2.1. The production deficits in agrammatism

Agrammatic speech is characterized as non-fluent, with a reduced speech rate and word finding difficulties. The functional words (i.e., articles, connecting words or auxiliaries) are more affected than content words (i.e., adjectives, nouns and verbs); in some cases functional words can be completely omitted (Albert, Goodglass, Helm, Rubens, & Alexander, 1981, p. 153). In agrammatic speech, nouns are more common than verbs. When verbs are used, they are often nominalized; they lack both free and bound grammatical morphemes and agreement for person, number and gender is usually omitted (Goodglass & Menn, 1985).

The agrammatic speech pattern is sometimes referred to as *telegraphic speech* and when listening to agrammatic aphasics, the general impression is that the subject knows what he wants to say but has great difficulties doing so. To further illustrate this speech pattern see the following examples (1), (2) and (3), produced by agrammatic speakers of English showing distinct features of agrammatism (from Badecker & Caramazza, 1985):

    (1)   Omission of functional words and inflectional omission:
            My uh mother died…uh…me…. Uh fi'teen. Uh, oh, I guess six month…my mother pass away. Ah' uh…an'en…uh…ah…. seventeen…seventeen…go uh High School.

(2)   Omission of verbs (in describing a picture of a girl giving flowers to a teacher):
       The young…the girl…the little girl is…the flower.

(3)   Nominalization used instead of verbs (same situation as in 2):
       The girl is…is roses. The girl is rosin'.

Not only does the substantial heterogeneity among individuals make the study of agrammatism particularly challenging, but these deficits do not necessarily occur to the same extent when comparing them cross-linguistically; many features described above are language specific (i.e., they occur in some languages but not in others). Menn and Obler (1990) collected studies from 14 languages reporting agrammatic patterns based on case studies of agrammatic participants. In Finnish, only a small number of inflectional errors appeared, and the aphasics' speech patterns appeared to be syntactically, rather than morphologically, agrammatic (Niemi, Laine, Hanninen, & Koivuselka-Sallinen, 1990). The authors argued that in synthetic languages, (i.e. Finnish), bound morphemes are not lost as is the case in analytic languages (i.e. English).

In Hebrew, a language with a rich inflectional morphology, the opposite pattern was manifested, that is, syntactic abilities were more affected than morphological ones (Baharav, 1990). Moreover, the *omission* of morphological units was replaced by the *substitution* of different morphemes. Another study shows a dissociation between production of tense and agreement inflection in Hebrew. Agreement inflections stay intact, while tense inflections tend to be impaired (Friedman & Grodzinsky, 1997; Friedman, 2006).

In Japanese, morphemes cannot stand on their own and therefore substitution for incorrect morphemes rather than their omission would be predicted. However, data from Japanese revealed that neither omission nor substitution were present in agrammatic speech (Sasanuma, Kamio & Kubota, 1990). The authors of this study argue that Japanese morphemes are word-internal and cannot form agreements across phrases as is the case in Indo-European languages. Thus, they may be more resistant to loss.

Chinese language does not have inflectional morphology and expresses the relations among sentence unites with the use of prepositions or word order. It has been

observed that Chinese agrammatic speakers produce no tense and agreement errors, omissions or substitutions (Packard, 1990). The preserved use of these grammatical features conveyed by grammatical devices other than morphology suggests that the deficits observed in agrammatic speakers of other languages may be related to the grammatical means by which certain functions are expressed, rather than to the function itself.

Moreover, variety across individuals within one language is not uncommon either. While some agrammatic speakers may have production difficulties but preserved comprehension (Miceli, Mazzucchi, Menn, & Goodglass, 1983; Fyndanis, Varlokosta, & Tsapkini, 2013), others may experience difficulty in production of some types of inflectional forms compared to others (Tsapkini, Jerema, & Kehayia, 2001; Druks & Froud, 2002).

2.2.   Comprehension deficits in agrammatism

While the production impairments and the telegraphic speech patterns can be easily recognized in agrammatic aphasia, comprehension deficits associated with agrammatism are less apparent. In fact, comprehension difficulties stayed largely unrecognized up until the 1970s when it became clear in the studies of Caramazza and Zurif (1976) that agrammatic aphasics exhibit difficulties in those types of sentences in which interpretation requires knowledge of syntactic structure.[3]

This subtle deficit can be detected only when using tasks such as sentence-picture matching or sentence-picture verification (for further discussion on these methods see Chapter 3). When employing such tasks, it has been observed that *non-canonical reversible sentences* are especially difficult to understand in agrammatic aphasia. In English, the canonical word order is S-V-O (subject-verb-object), but for example in Japanese it is S-O-V, and this base word order varies across languages. In general, sentences that have their major content words in canonical positions (e.g. simple active sentence structure – *the boy kissed the girl*) are easier to comprehend in agrammatic aphasia than sentences in which the constituents have been moved from their canonical

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[3] Even though it seems that Erich Salomon (1914) was the first one to propose the existence of a syntactic comprehension deficit in agrammatic aphasia, this idea was rejected by his contemporaries in the early 20th century (Bastiaanse & Thompson, 2012, 3).

positions (e.g. passive sentence structures – *the boy was kissed by the girl*). Comprehension deficits especially arise in semantically reversible sentences. A sentence is considered semantically reversible if, after the noun phrases (NPs) have mutually exchanged their positions, the sentence still makes sense as seen in the Example (4). In irreversible sentence structures, the same NP exchange results in ungrammatical sentence as illustrated by the Example (5).

(4)   *The girl was chased by the boy. / The boy was chased by the girl.*

(5)   *The apple was eaten by the boy. / *The boy was eaten by the apple.*

In the case of reversible passives, the meaning cannot be derived from the lexical units or other, pragmatic, clues. This is probably the reason why reversible passives are more problematic compared to relatively unimpaired irreversible passives. In relatively unimpaired irreversible passives aphasics can rely on other clues apart from the syntactic structure to interpret the sentence meaning. However, in reversible passives aphasics do not have any outside clues that would help them to interpret the sentence. Other problematic sentence structures are *object relative clauses* (6) but, conversely, *subject relatives* (7), where the first NP is an agent of the sentence, are relatively unproblematic. Similar patterns can be observed in *object clefts* (8) that cause bigger problems in comparison to *subject clefts* (9):

(6)   *The girl that the boy was chasing was blond.*

(7)   *The boy that is chasing the girl is blond.*

(8)   *It was the boy that the girl was chasing.*

(9)   *The boy is chasing the girl.*

Even though this phenomenon has been observed in many cross-linguistic studies in English, Dutch, German, Italian, Turkish or Czech (e.g., Bastiaanse & Edwards, 2004; Burchert & De Bleser, 2004; Luzzatti, Toraldo, Guasti, Ghirardi, Lorenzi, & Guarnaschelli, 2001; Yarbay, Altinok, Özgirgin, & Bastiaanse, 2011; Hudousková, Mertins, Flanderková, & Tomšů, 2014), it can vary across languages depending on

word order grammatical constraints. Languages that allow distinct syntactic orders such as object-verb-subject (O-V-S) or object-subject-verb (O-S-V) seem to affect the comprehension of agrammatic speakers in a different manner than purely S-V-O languages such as English (for review on agrammatic comprehension see Grodzinsky, 1999; Grodzinsky 2000). For instance, Friedman and Shapiro (2003) found relatively unproblematic comprehension of S-V-O sentences in Hebrew agrammatic aphasics compared to comprehension of O-S-V and O-V-S sentences. Comprehension of structures that involve NP movement was impaired in Hebrew speakers, regardless of the grammatical aspect. Japanese and Korean also have relatively free word order in comparison to English, as they allow the object to be moved to the position preceding the subject (O-S-V). Hagiwara & Caplan (1990) found at chance performance on these types of sentences in Japanese aphasic speakers. Beretta and colleagues reported a similar pattern in Japanese and Korean (Beretta, Schmitt, Halliwell, Munn, Cuetos, & Kim, 2001). Thus, even simple active sentences may cause problems for listeners of Hebrew, Japanese or Korean (This issue will be further discussed in Section 2.4 of this chapter, and in Chapter 4 with respect to the *representational accounts)*.

Despite the cross-linguistic variability, some structures appear to be more difficult to interpret than others in agrammatic aphasia. Theories that attempt to explain the underlying cause of these difficulties usually take one of two approaches: 1) *processing accounts* or 2) *representational accounts.* The former explain the deficit as being caused by disrupted grammatical representations, the later state that the grammatical representation is preserved, but that processing mechanisms necessary to carry out complex sentence comprehension tasks are impaired (for further discussion on processing and representational accounts see Chapter 4).

2.3.   Reading and writing modalities

Goodglass argues that "cross-modal comparisons are of vital importance in identifying the level in language processing at which the agrammatic symptoms arise" (Goodglass, 1990, p. 1365). If the grammatical representations were impaired in agrammatism, one would expect the problems that arise in comprehension and production modalities to appear in reading and written form as well. Contrarily, if grammatical knowledge was

preserved but the processes that convey the morpho-syntactic operations were impaired we would expect fewer problems in writing and reading.

However, evidence from the oral reading modality studies in agrammatism is rather mixed. Some studies report asyntactic reading that mirrors the comprehension deficits seen in agrammatism (i.e., semantically reversible non-canonical structures are impaired). Similarly, reading deficits in agrammatism can be manifested as an inability to read aloud those items (e.g., functional words, affixed words etc.) that are omitted in spontaneous agrammatic speech (Caramazza, Berndt, & Hart, 1981). Interestingly, the ability to read non-words may be disrupted in agrammatism (Drunks & Froud, 2002). These disruptions suggest that both writing and reading are mediated through the oral system. However, others report no or minimal reading impairment, and reading at a faster rate than oral production (for review see Goodglas, 1990). Kolk and colleagues argue that this absence of reading impairment may be caused by a reliance on grapho-phonemic operations while reading, whereas syntactic or morphological processes are irrelevant (Kolk, Heling, & Keyser, 1990).

The same features problematic in production are often disrupted in writing. Some authors report an even bigger reduction of syntax in written form compared to oral form; agrammatic speakers may produce much less language using writing as opposed to an oral narrative accompanied by a greater reduction in syntax compared to oral speech (Goodglass, 1990). Unfortunately, as Goodglass put it, both writing and reading patterns are highly variable in agrammatic aphasia, which opens the door to "endless *ad hoc* explanations of differences between modalities in agrammatism" (Goodglass, 1990, p. 1366).

2.4. Agrammatism in Czech

Numerous English studies on agrammatism do not leave many questions there to be answered in understanding English agrammatism. German, Dutch, Hebrew and Italian have also all been the languages of study in many experiments on agrammatism. However, there have not been many studies on agrammatism in Slavic languages, (i.e. Czech), and thus, there may be many agrammatic features yet to be discovered in these languages. Why is it necessary to study agrammatism in Czech speaking patients? There are at least two aspects inherent to Czech grammatical structures that cause

Czech agrammatic speakers to behave differently from English agrammatic speakers: 1) *word order* and 2) *rich inflectional system.* Furthermore, there is some evidence that Czech speakers handle *argument structure complexity* differently than English speakers (Flanderková, 2015). Therefore, it may be useful to compare agrammatic speech in Czech with what we know from other languages, including English. The following section aims to address all these issues.

2.4.1. Morphology

Czech is classified as synthetic, inflectional (or fusional) language that is relatively rich in inflective morphemes. Thus, one could theoretically expect to observe even more frequent omission of free and bound morphemes in agrammatic speech compared to languages not as rich in their morphology (e.g., English). However, this is not precisely the case, as Czech aphasics tend to erroneously substitute morphemes with other morphemes, instead of simply omitting them. Lehečková (2009) states that these morphological deficits are driven by the typology of a given language. She argues that grammatical morphemes can be completely omitted only in isolating languages (e.g., English), or possibly in agglutinative languages (e.g., Finnish). In inflectional languages (e.g., Czech) the morphemic omission could result in a bare word root, but Czech words often cannot stand without a morpheme, as missing a morpheme would simply create a non-word [e.g., *velký* (*big* in the 3rd person sing.) */ *velk* (the 3rd person sing. marker omitted)*; přišel* (*he came*) */ *přiš* (the tense and case morphology omitted); *kadeřnice* (*a woman hairdresser*) */ *kadeřni* (the genrer marker omitted)]. Based on the previous observations, Czech aphasic speakers do not form such non-words (Lehečková, 2009). Thus, in Czech, the morphemes are not omitted but rather erroneously substituted. Lehečková further observed that Czech agrammatic speakers omit mainly functional words and auxiliaries as opposed to morphemes (Lehečková, 2009, p. 30). She summarizes that agrammatism in Czech is manifested by two means when it comes to oral production: 1) *erroneous substitution* (discussed above) and 2) *omission of functional words*. The examples (10) and (11) below show such utterances (from Lehečková 2009, 26) typically produced by Czech agrammatic speakers.

(10) Substitution: nominative in place of accusative:
    Doctor nezná moje dcera. / Doctor does not know I daughter.

(11) Omission of functional class words (here preposition):
    Chodim furt --- nemocnice. / I often go --- hospital.

Lehečková (2009) further generalizes that Czech agrammatic speakers tend to substitute feminine and neutral gender markers for the masculine one; plural markers are often substituted for singular ones. When it comes to cases, the most used case in agrammatism is nominative in 3rd person singular form. Substitution of past and future tense for the present tense is also typical, and imperative and conditional forms for indicative forms and passive sentences are substituted for actives. These patterns indicate that the forms that are more frequent and canonical serve as a substitution for forms that are not as frequent, or those that are non-canonical. Such forms are referred to as *default forms* (Lehečková, 2009, pp. 27-33).

2.4.2. *Morpho-syntax and word order*

In inflectional languages, such as Czech, the inflectional morphology is an important device that produces cohesion in the text. The identification of morphological suffixes in nouns is an essential indicator of the thematic roles and their relations, while verbal tense and aspect markers are vital for interpreting the continuity and direction of the action. In this respect, inflectional morphology directly affects the comprehension on the sentence level, because morphological suffixes are the point where the two levels of morphology and syntax cross.

Inflectional languages (e.g., Slavic languages) usually permit variation in basic word order, because the morphology of these language systems provides enough information to convey basic semantic/syntactic relations (Bates, Friederici, & Wulfeck, 1987, p. 551). For example, while in English syntactic order is the device used to express the grammatical relations, Czech grammar employs a morphological system of agreement of person, number, gender and case that allows for relatively free word order. Canonical S-V-O word order (e.g., *Lovec zabil medvěda. / The hunter killed the bear.*) can be replaced by O-V-S word order (e.g., *Lovce zabil medvěd. / The bear killed the hunter.*), and Czech speakers rely more heavily on morphological agreement to

correctly assign thematic roles. Assuming that the impairment of inflectional morphology in agrammatism is one of its main symptoms, one might conclude that Czech agrammatic speakers have bigger problems in production and comprehension on the syntactic level compared to English agrammatic speakers.

Non-canonical word order deficits in Czech were tested in a recent study (Hudousková et al., 2014) that investigated the comprehension of active and passive sentences in a sentence-picture matching task. Accuracy rates indicated that Czech speakers exhibit a similar disruption pattern of semantically reversible non-canonical sentence structures (i.e., responses at chance rate) as agrammatic aphasics in other languages. Hudousková and colleagues (Hudousková et al., 2014) further discuss case knowledge (i.e., the instrumental case in passives), and argue that it helps patients to interpret irreversible structures, but that this case knowledge may confuse them when interpreting reversible structures. However, the exact role that Czech case morphology plays in sentence processing of reversible and irreversible structures needs to be further investigated.

With regard to syntactic comprehension in Czech, Flanderková (2015) further investigated processing of different types of ungrammatical sentences in a grammaticality judgement task. The results revealed at chance performance on sentences that violated the inflectional case morphology (e.g., *Otec očekával odpověď sestru / *The father expected the sister answer*) as well as in the sentences with argument structure error (e.g., *Alice snědla / Alice ate*). The sentences that violated the inflectional morphology and argument structure but had one more optional sentence element inserted (e.g*., Martin smrká kapesník / Martin is blowing the tissue* or *Teta včera navštívila / *The aunt visited yesterday.*) were less problematic. Flanderková suggests that due to impaired morpho-syntactic processing, Czech aphasics may rely more on lexical clues to interpret sentences rather than on the inflectional morphology and argument structure. This would be consistent with her observation that the more optional information that is inserted into the sentence, the better aphasics detect the grammatical mistake. However, such an interpretation is inconsistent with previous grammaticality judgement studies in English (Kim & Thompson, 2000).

Finally, Flanderková (2015) studied the comprehension of thematic and rhythmic information in Czech agrammatic speakers in an altering word order task. The results revealed that agrammatic speakers exhibit reduced ability to identify sentences with unsuitable word order where theme and rheme were mismatched. These results suggest

that Czech agrammatic speakers experience lower sensitivity to word order and thematic arrangement. This difficulty may stem from the morphology impairment discussed above and/or from a higher level syntactic impairment.

In conclusion, there are some common, cross-linguistic patterns observable in all agrammatic speakers. However, there is also high variability among languages, arising from their specific grammatical devices, and allowing for some agrammatic features to manifest to different degrees than others. Czech speakers show agrammatic patterns similar to other inflectional languages with rather free word order. Among these is the substitution of inflectional morphemes that are less frequent with those that are more frequent, and the omission of functional words. In the comprehension modality, Czech agrammatic speakers tend to perform well on sentences with basic word order, but their performance is only at chance or slightly above chance on sentences with non-canonical word order in both grammatical judgement and sentence-picture matching tasks.

An experiment employing eye-tracking method to test passive sentence comprehension in Czech agrammatic aphasics is presented in the Experimental Section of this thesis. The results featured in this section shed more light on non-canonical sentence comprehension in Czech, and discuss some issues mentioned in this chapter in context of selected theories of agrammatic sentence comprehension, that are reviewed in the Chapter 4.

3.   Experimental methods in agrammatism research

Experimental methods are used to test concrete research hypotheses inferred from linguistic theories and models. Distinct methods can be uniquely suited to answer different types of experimental questions, and the choice of method also determines the way in which the data will be processed, and how the results will be analyzed statistically. Therefore, it is essential to have a general overview of different types of experimental paradigms, as well as knowledge of the advantages and disadvantages of a particular method, before employing it in the particular experiment. The aim of this section is to draw basic distinction between *off-line* and *on-line* methods, to introduce the most common experimental paradigms and tasks used in the research of agrammatism, and to evaluate their advantages and disadvantages.

3.1.   Basic classification: *off-line* and *on-line*

The terms *off-line* and *on-line* reflect the degree to which a given method has access to the underlying psychological or neuronal processes. While the off-line methods have no direct access to these processes and reflect only the outcome or final product of the participants' performance or decision (e.g., in the questionnaire or in the picture naming task), the on-line methods offer mediated access to the processes that sub-serve the participant's performance. Thus, on-line methods are capable of capturing somewhat automatic and unconscious processes that would be otherwise unobservable using off-line methods; they can measure either behavioral responses such as eye-fixation patterns (e.g., eye-tracking), detect the electrophysiological response (e.g., event related potentials or ERPs), capture the blood oxygenation level signal (e.g., functional magnetic resonance imaging or fMRI) or magnetic field generated by the neuronal activity (e.g., magnetic resonance imaging or MEG).

Over the years, the methods used in the research of agrammatism have advanced thanks to access to modern technologies and new methodological perspectives. In the past four decades, the methods used in this domain were mainly off-line, measuring accuracy rates, reaction times, rating grammatical judgement or transcribing the grammatical constructions reported by agrammatic participants. These types of off-line

methods can access the outcome of the task but do not allow us to analyze language processing in real time. Therefore, more recent studies have employed on-line measurement techniques such as eye-tracking, event-related potentials or neuroimaging techniques that have allowed researchers to analyze the automatized and unconscious language processes in real time. The combination of both off-line and on-line methods brought a substantial amount of new evidence into understanding the nature of deficits in agrammatism, and has shaped the theoretical discussion on agrammatism (Thompson & Bastiaanse, 1012, pp. 10-12).

3.2.   Off-line experimental approaches

As in the early days, it is still common to use paper-and-pencil questionnaires and simple production tasks to test the comprehension and production deficits in agrammatism. Both the behavioral *accuracy* and *reaction times* (RTs) can be recorded in the off-line tasks to quantify and compare the aphasics' performance.

3.2.1.   *The production modality off-line tasks*

Examples of common tasks designed to investigate agrammatic production are *picture naming*, *picture description,* or *sentence completion* tasks, that are used to evaluate grammatical morphology or syntactic deficits. *Cross-modal lexical priming* can be used to investigate lexical activation deficits. (Thompson & Bastiaanse, 2012, p. 11).

However, motor deficits that can overlap with or mask the morphological and syntactic deficits are a common obstacle in experimentally testing production in agrammatism. Thus, it may be difficult to disentangle the real source of a patient's struggle in production. Disrupted processing resources and executive functions in patients, such as planning, working memory impairment and others, may also be involved in speech deficits in agrammatism. Thus, it is essential to perform a detailed assessment on every patient before the experimental study.

3.2.2. *The comprehension modality off-line tasks*

Agrammatic comprehension can be tested in a *sentence-picture matching task*, where participants are asked to match the sentence to one of the presented pictures and the performance accuracy is analyzed by calculating the percentage of correct and incorrect responses. Accuracy rates in this task have been "the basis for most deficit analysis in this area of aphasiology" (Caplan et al., 2004, p. 64). Since participants are asked to decide which picture matches with the sentence, the nature of error is governed by the introduced distractors, and participants are likely to get some items correct by chance (Webster & Howard, 2012, p. 148). Therefore the percentage of correct responses is calculated in relation to chance level (i.e., 50% in binary choice presentation). Thus, the final score has three possible outcomes: above chance, below chance, and at chance. Above chance is considered to reflect a relatively preserved sentence comprehension. Below chance performance suggests application of some erroneous rule or strategy that systematically results in incorrect sentence interpretation. At chance performance has been argued to reflect guessing, that is, a random choice between two alternative interpretations (Hanne, Sekerina, Vasishth, Burchert, & De Bleser, 2011).[4]

A similar, commonly used task in off-line research of agrammatic comprehension is a *sentence-picture verification task*, in which participants are asked to verify whether the aurally (or textually) presented sentence corresponds to the presented picture. Other widely used tasks in this domain are the *object-manipulation task,* in which participants are instructed to manipulate given objects (e.g., paper dolls) to act out the provided sentences, or the *grammaticality judgment task* where participants assess the grammatical well-formedness of presented sentences (e.g., Caplan, Waters, Dede, Michaud, & Reddy, 2007).

3.3. On-line experimental approaches to agrammatism

The majority of studies in agrammatism have traditionally used the common off-line tasks mentioned in the previous section. However, the performance derived from off-line data can "mask the nature of underlying on-line processing deficits" (Wassenaar &

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[4] It is necessary to note that there has been a long lasting debate on whether at chance performance in sentence-picture matching task observed in non-canonical sentence structures in agrammatism actually reflects guessing. Thanks to the evidence from the on-line methods this view has recently been reevaluated (this issue will be further discussed in the Chapters 4 and 5).

Hagoort, 2007, p. 739). In order to get a better idea of real time processing and its time course, off-line tasks are often combined with on-line paradigms. Many authors have convincingly argued in favor of employing on-line and off-line tasks simultaneously, as such a paradigm could provide new insights into the nature of the underlying comprehension deficits (e.g., Caplan et al., 2007; Dickey, Choy, & Thompson, 2007; Hanne et al., 2011). There are a number of on-line approaches that have been used to examine agrammatism, particularly verb and sentence processing in both the production and comprehension domains. These include *self-paced reading or listening*, *cross-modal lexical priming, anomaly detection* or *eye-tracking paradigms*. These paradigms are usually combined with an off-line task, such as sentence-picture matching or grammaticality judgement. Such methods can potentially inform us, not only about what structures are impaired, but also about what structures are more difficult to process than others, and what capacities agrammatic speakers maintain in order to perform distinct syntactic operations (Thompson & Bastiaanse, 2012, p. 11).

3.3.1. Self-paced reading or listening task

A *Self-paced reading or listening task* (e.g., Caplan et al., 2007) is executed with the use of an auditory or textual *moving window paradigm*. In this task, the participant is asked to read or listen to a sentence phrase-by-phrase or word-by-word by pressing a button as fast as possible. The participant is then asked to perform sentence-picture matching or to make a grammatical judgement at the end of the sentence. Each button press is recorded, which provides insight into how fast participants process the sentence units. The assumption behind this task is that the RTs for particular lexical items reflect the time it takes the participant to integrate these items into the syntactic or semantic structure of the sentence. The longer the latency, the higher the demand to integrate these items (Caplan et al., 2007, p. 118). In the course of agrammatism, such a task is suitable when investigating the time course of sentence processing in relation to accuracy. However, listening to a sentence in a word-by-word manner is not considered reflective of natural sentence processing and comprehension (Thompson & Choy, 2009, pp. 259-260), which is the main limitation of this technique.

3.3.2. *Cross-modal lexical priming*

Cross-modal lexical priming (CLP) is a task designed to detect the activation of lexical or syntactic information in real time during sentence comprehension (e.g., Zurif, Swinney, Prather, Solomon, & Bushell, 1993; Swinney & Zurif, 1995). This task depends on the effects of lexical priming, in which one presented word facilitates lexical activation of another, semantically related, word. For example, a participant listens to the sentence *"the gardener left the house"*, and at a relevant point in the sentence he is presented with a word on the computer screen. Subsequently, he is asked to make a lexical decision (e.g., decide if the presented item is a word or a non-word) by pressing a button as fast as possible. The idea is that items related to gardener, such as *seed*, are processed faster than unrelated items. The priming effect indicates that the word *gardener* in the previously presented sentence has been activated (Zurif, Swinney & Garrett, 1990).

This task is suitable for investigating gap filling capabilities in sentences involving syntactic movement, which can be problematic for agrammatic aphasics. However, the dual nature of this language task (i.e., listening to the sentence while performing a lexical decision task) is argued to increase the demands on the process and interfere with natural language processing (Thompson & Choy, 2009, pp. 159-160).

3.3.3. *Anomaly detection task*

Another on-line behavioral task, the *anomaly detection task* (e.g., Dickey & Thompson, 2004), has been designed to investigate syntactic movement and its comprehension. In this task, participants are asked to press a button upon hearing something odd in a presented sentence. Both the RTs and accuracy are recorded to detect anomalies in agrammatic syntactic comprehension. This task may be combined with the ERP method. Different sensitivity to certain types of grammatical errors during sentence processing can inform researchers about the types of syntactic operations that are more difficult for agrammatic speakers. Unfortunately, this task does not reflect natural language processing because the sentences are manipulated to include errors. Participants are asked to overtly report on these errors, which can again increase the demands required to execute the task. These demands reach beyond the cognitive load required in routine sentence comprehension.

3.3.4. Eye-tracking paradigm

Probably the most widely used paradigm in on-line research of comprehension in agrammatism within the last decade is the *eye-tracking-while-listening paradigm* (e.g., Dickey, 2007; Thompson & Choy, 2009; Hanne et al., 2011; Meyer, Mack, & Thompson, 2012). This paradigm employs a camera that tracks the participants' eye-movements at a high sampling rate (60 - 250 Hz) while they gaze at visual stimuli. Even though the eye-tracking paradigm does not necessarily require a direct response, it can be combined with other behavioral tasks such as sentence-picture matching or picture-verification tasks. The eye-movements are time-locked to auditory stimuli within 200 ms (Altman & Kamide, 2004) so as to compensate for the slow-down associated with the execution of the eye movements.

The successive analysis of the changes in location of allocated visual attention provides mediated access to the strategies applied in problematic sentence structures, and reveals how these patterns deviate from the normal fixation patterns in healthy populations. This method enables an experimenter to analyze the processing of the entire sentence as it unfolds in real time. Thus, it is not limited only to the critical sentence regions, as is the case with the previously mentioned on-line methods such as a CLP, or an anomaly detection task (Thompson & Choy, 2009).

Even though eye-tracking is mostly employed in studies investigating comprehension, it has also been used in the production domain, for instance, to examine the processing costs in production of distinct grammatical structures in agrammatism (e.g., Cho & Thompson 2010; Lee & Thompson, 2011).

3.3.5. Event-related potentials

The use of electro-encephalography (EEG) with the measurement of the *event-related potentials* (ERPs) provides high temporal resolution, and allows detailed investigation of time course of language processing in agrammatism (e.g., Wassenaar & Hagoort, 2007; Kielar, Meltzer-Asscher & Thompson, 2012). Access to highly automatized processes is mediated by means of measuring the peaks in electrical brain activity in response to presented stimuli. For this reason, the ERPs must always be studied in relation to the stimuli that evoke them. Stimuli in the research of agrammatism often include semantic or grammatical mismatch (e.g., semantically unfitting item,

morphological anomaly or syntactic error), and may be combined with the anomaly detection task discussed above.

The rationale of the ERP studies is based on particular ERP components that have been argued to reflect different types of processes. For example, the P600, a positive deflection with onset of 500-600 ms after the presented stimuli, is elicited by grammatical errors. The N400, a negative deflection that peaks around 400 ms post-stimulus onset, is argued to be reflecting (among other things) lexical integration. Studying these components in relation to distinct linguistic stimuli can inform us about the anomalies that appear early in stimuli processing, and may possibly underlie deficits found in agrammatism.

3.3.6. Neuroimaging techniques

While ERPs are better suited for investigating the time-course of language processing in agrammatism, localization of certain neuronal activity can be achieved with the use of neuroimaging methods. Thanks to high spatial resolution, neuroimaging techniques such as *positron emission tomography* (PET), *magnetic resonance* (MR), *functional magnetic resonance imaging* (MRI) and *magnetoencephalography* (MEG) provide exquisite anatomical details of lesion size and location, and inform us about the typical patterns of anatomical changes that occur during the brain's recovery (e.g., Thompson, Riley, den Ouden, Meltzer-Asscher, & Lukic, 2013). This provides us with crucial information as to where specific language functions reside in the brain, and what parts of the brain take over if the given area has been damaged (for review see Thompson & den Ouden, 2008).

Even though functional imaging methods have been under-utilized in the study of agrammatism compared to other on-line methods, new studies investigating neural correlates of agrammatism are emerging. For instance, Schönberger et al. (2014) argue that studying specific brain activation patterns associated with agrammatic errors could contribute to the understanding of functional processes and neural correlates of agrammatism, and such findings may lead to new brain stimulation studies.

3.3.7. Transcranial magnetic stimulation

Transcranial magnetic stimulation (TMS) is gaining an increasing role in the assessment of the functions of distinct brain areas involved in agrammatism, as well as in aphasia therapy. It has been observed that the transcranial magnetic stimulation applied with appropriate frequency, intensity and duration can lead to an increase or decrease in the excitability of the targeted brain area with long lasting effects (Caplan, 1989, p. 417).

Stimulation by high frequencies (> 1 Hz) increases the excitability of selected brain areas, and thus, can enhance performance on linguistic tasks in agrammatism. For example, Szaflarski and colleagues applied excitatory rTMS to the affected Broca's area, and reported improved language skills in patients with chronic post-stroke aphasia (Szaflarski, Vannest, Wu, DiFrancesco, Banks, & Gilbert, 2011).

Stimulation at low frequencies (< 1 Hz) inhibits selected brain areas for an extended period of time. This can help to modulate the bilateral malfunctioning that often appears as a consequence of spontaneous recovery in aphasia. For example, the right Broca's area tends to be "over-activated" following stroke, and this over-activation has been argued to correspond to a maladaptive strategy. Suppression of this maladaptive bilateral functioning can result in language improvement. For example, Naeser and colleagues (Naeser et al., 2005; Naeser et al., 2011) applied repeated inhibitory stimulation to the right Broca's area of non-fluent aphasics, which led to significant improvements in picture naming tasks, and a decrease in RTs in executing these tasks.

Even though transcranial magnetic stimulation has not been standard practice in the treatment of agrammatism nor is it commonly employed in its research, this technique has an undeniable potential to become an invaluable tool in the laboratories of agrammatic researchers and speech therapists.

3.4. Evaluation of on-line and off-line methods

In this chapter, I have argued that off-line methods are suitable for assessing the success or failure in comprehending selected types of sentences. The main advantage of off-line tasks is the relative ease of execution (as all one needs is a pen and paper), and the little to no cost involved. The output is relatively straight-forward, which facilitates

data processing and statistical analysis. By means of off-line methods, researchers can get a better idea of the agrammatic patients' performance on particular tasks, and such data can consequently help to generate specific hypotheses relevant to further experimental testing. The main disadvantage of off-line methods is that the resulting data do not reflect the language processing *per se,* but only the final response, which does not tell us much about the nature or course of the processes that led to the response. This is why the abovementioned tasks originally executed in off-line modes have been recently replaced by, or at least combined with, more advanced paradigms and techniques that allow access to real time sentence processing.

On-line paradigms provide access to real time cognitive or neuronal processes. These paradigms are suited for testing the time-course of automatic and unconscious processes, and can be especially informative in combination with other off-line tasks. However, even these methods are not flawless. As Thompson and Choy argue, anomaly detection task or CLP can only inform us about the selected parts of the sentence into which the anomaly or lexical probe has been placed, and thus, they cannot provide us with the full picture of how the sentence processing proceeds (Thompson & Choy, 2009, p. 258). Another disadvantage of behavioral on-line measures that require pressing a button, such as CLP, self-paced listening or anomaly detection, is a certain slow-down. The reactions of agrammatic speakers can be slowed by the malfunctioning of related motor areas. Apart from this slow-down, the execution of the button press or lexical decision required during the task increase the task complexity and can influence the performance on the task, as Thompson and Choy (2009, p. 259) argue. Finally, none of these behavioral on-line methods allow us to reflect natural sentence processing. Detecting anomalous words, processing and pacing sentences word-by-word or performing tasks that require dual language task performance cannot be considered entirely natural language processes.

In contrast, the eye-tracking-while listening paradigm does not rely on any overt behavioral response, even though sentence-picture or sentence-verification tasks can be added as supplementary accuracy measures. The eye-tracking paradigm is capable of capturing more automatic processes accompanying comprehension, because the eye-movement fixations are automatic and unconscious. Moreover, the eye-movement recording is continuous, and thus, this method can give us information about eye-gaze fixation positions at any time in the sentence as opposed to the other on-line behavioral methods. Measuring eye-gaze patterns while participants listen to incremental

sentences is not considered to be as unnatural as the previous paradigms. However, eye-gaze patterns and eye-movements are also slowed relative to the automatic brain processing that takes place before any behavioral changes can be observed.

The highly automatic processes underlying linguistic tasks can be detected by measuring the ERPs that provide an immediate measure of the brain's response to the stimulus. This excellent temporal resolution is especially suited to investigating the malfunctioning of immediate brain responses in the agrammatic population. However, the spatial resolution of ERPs is rather poor, leaving this method better suited to answering questions related to the time course of processes and their deficit, rather than to their location. The biggest disadvantage of ERPs is that it is often unclear as to what exact function the ERP components play in language processing. Even though the researchers can assume what certain ERP components correspond to, they remain uncertain about the specific biophysical events that underlie the production of a given ERP. On the contrary, the interpretation of the behavioral response of a given participant is quite clear (Luck, 2014, p. 22).

Neuroimaging methods have high spatial resolution, and are capable of answering questions related to specific neural networks and areas responsible for particular linguistic tasks or deficits. However, neuroimaging is very expensive and highly time consuming with respect to design, execution, data processing, and analysis. Researchers applying neuroimaging techniques are dependent on a number of complicated statistical procedures and require specific tools for data analysis and visualization (Huettel, Song, & McCarthy, 2009). Finally, neuroimaging data is quite difficult to interpret. The images can tell us what areas of the brain are activated at a given time, but they do not tell us what it means and why these areas are activated. Many areas can be active in response to any given task, but that does not necessarily mean that these particular areas play an important role in a given task. Because it can be difficult to interpret what causes brain activity, neuroimaging studies have to be designed based on a sound theory of language processing and brain structure if they are to provide us with any meaningful clues about what is going on in the brain during the task (Harley, 2014, p. 21).

To conclude, despite all the disadvantages that on-line paradigms come with, it is perhaps needless to add that on-line techniques have revolutionized the study of agrammatism. Taking into consideration all the above mentioned characteristics of on-line techniques employed in the study of agrammatism (Table 3.1.), the eye-tracking-

while-listening paradigm has got all the attributes necessary to investigate the automatic sentence comprehension in agrammatism. Therefore this paradigm has been employed in the active and passive sentence comprehension experiment reported in The Experimental Part of this thesis.

Table 3.1. Characteristics of on-line behavioral and neurophysiological methods applied in sentence processing research of agrammatism.

Task/Characteristics	Reflects natural language processing	Captures automatic processes	Requires overt response	Data analysis and interpretation demands	Costs
Self-paced listening/reading	no	no	yes	Low	low
Cross-modal priming	no	no	yes	Low	low
Anomaly detection	no	no	yes	Low	low
Eye-tracking-while-listening	yes	yes	no	moderate	low
Event-related potentials	yes	yes	no	high	low
Neuroimaging	yes	yes	no	high	high

4. Theoretical perspectives on comprehension deficits in agrammatism[5]

The preceding chapters defined agrammatism as consisting of both production and comprehension difficulties. The production modality has been discussed in the previous sections to provide the reader with the information necessary to understand the syndrome of agrammatism in its complexity. From now on, the thesis is going to focus on the comprehension impairment that is the main focus of the experiment presented in the Experimental Part. It is not within the scope of this thesis to discuss theoretical approaches to both production and comprehension. However, they should be studied in relation to each other rather than as separate modalities, as argued later in this Chapter.

Regarding the theoretical approaches to comprehension, there are two theoretical streams attempting to explain the comprehension difficulties in agrammatism: *representational accounts* and *processing accounts*. This chapter provides a brief overview of the past research of comprehension deficits in agrammatism and offers an overview of the two distinct theoretical approaches. Additionally, particular hypotheses are compared and evaluated in the light of some recent evidence from linguistic research on agrammatism.

4.1. Past research on comprehension deficits in aphasia

Up until the 1970s, agrammatic aphasia, (at the time often interchangeably called Broca's aphasia), was associated exclusively with impaired language production (as discussed in the Chapter 1). At that time, Wernicke's aphasia was considered characteristic of impaired language comprehension abilities. Experimental research conducted by Zurif and Caramazza (1976) showed systematic deficits in language comprehension in agrammatic aphasia, leading to a new understanding of how to diagnose and classify aphasic language impairments. These systematic deficits not only called for research on a theoretical underpinning of aphasia, but also brought about a

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[5] This chapter is a amodified version of the theoretical paper "Theoretical Perspectives on Comprehension in Agrammatic aphasia" elaborated by Pavlína Heinzová and Petra Chudárková within the project "Use of Eye-Tracking Technology in Research on Communication Disorders, IGA_FF_2014_046" and submitted to Czech linguistic journal *Slovo a Slovesnost*; currently is in the review process.

need to redefine the classical taxonomy of aphasia that had been established in the 19th century by Paul Broca and Carl Wernicke.

Zurif and Caramazza (1976) were the first to experimentally test comprehension in agrammatism using sentence-picture matching task. The results of that study showed that agrammatic individuals performed poorly on more complex sentence structures where the interpretation depended on syntactic relations. These findings lead to the large body of studies investigating comprehension difficulties in agrammatism across many languages (e.g., Thompson & Choy, 2009; Meyer et al., 2012; Bastiaanse & Edwards, 2004; Luzzatti et al., 2001; Burchert & De Bleser, 2004; Hanne et al., 2011, Yarbay et al., 201; Hudousková et al., 2014). These studies were in consensus on the sentence types that are difficult for agrammatic aphasics. Among these are non-canonical, semantically reversible sentence structures (e.g., passives, object relatives, object-cleft constructions and object questions). However, canonical structures in which the agent is linearly in the frontal position (e.g., active sentences, subject-cleft or subject relative clauses) are not problematic. Neither are semantically irreversible non-canonical structures (e.g., irreversible passives). Based on these commonalities, comprehension deficits in agrammatic aphasia are not random but follow some selective pattern of loss. Theoretical research in agrammatic comprehension is motivated by the belief that if we can explain these selective patterns within an adequate neurolinguistic theory, the link between the organization of language in our brain and our neurolinguistic theory shall be established (Beretta, 2008, p. 155). Moreover, if we manage to grasp the underlying principles of this comprehension impairment, we will be able to determine better forms of treatment for agrammatic aphasics.

Today there are two basic accounts which attempt to explain comprehension difficulties in agrammatic aphasia: *representational accounts* and *processing accounts*. The former hold that the core problem lies in the impairment of underlying syntactic representations (i.e., the ability to correctly use the grammatical knowledge is restricted), whereas the latter claim that comprehension is limited due to a more general, processing deficit. This more general, processing deficit causes agrammatic aphasics to perform poorly on comprehension tasks, but leaves underlying syntactic representations unimpaired.

4.2. Representational deficit accounts

According to *representational accounts*, deficits in agrammatic aphasics' comprehension abilities are due to an impairment in syntactic representations. These accounts are often formulated in terms of the Government and Binding Theory (Chomsky, 1981) where syntactic trees are used to explain deficits in syntactic operations or knowledge. Four theories with quite different approaches to the aphasia comprehension deficits are going to be introduced within the representational accounts: a) *the Trace Deletion Hypothesis,* which assumes deletion of traces within the syntactic movement, b) *the Pathological Slow-Down Hypothesis,* which tackles the slow-down in aphasics' syntactic linking, c) *the Double-Dependency Hypothesis,* which concentrates on hierarchy and word order, and d) *the Derived Order Problem Hypothesis*, which states that the derived word order is responsible for the difficulties in agrammatic comprehension. The following section introduces and evaluates each of these hypotheses.

4.2.1. The Trace Deletion Hypothesis

The Trace Deletion Hypothesis (TDH; Grodzinsky, 1995; 2000; 2006) is probably the most influential attempt to explain aphasic non-canonical sentence comprehension difficulties. The core idea of the TDH is that this comprehension deficits come from an inability to represent traces of movement in syntactic representations. According to this view, agrammatic aphasics resort to a *default strategy,* which results in above chance performance in active sentences, but only at chance performance in case of passives or object relative clauses. The TDH assumes that agrammatic aphasics have all the traces of syntactic movement deleted from their syntactic representation. In reversible non-canonical structures, such as *the woman was kissed by the man*, the theme *the woman* is moved from its base position and is co-indexed with its trace. In normal sentence processing, the thematic role of *the woman* can be assigned based on its trace. In agrammatic processing, traces are deleted from the grammatical representation which prevents the correct thematic role assignment. The agrammatic individual recognizes *the man* as an agent due to the *by*-phrase, but there is no thematic role assigned to *the woman*. Therefore, the *default strategy* is used, which means that *the woman* is assigned the agent role based on its linear position (in English, the first NP is usually an agent).

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This results in *double-agent representation*, that is, agrammatic individuals assign the agent role to both *the woman* and to *the man*. Thus, when the patients carry out standard sentence-picture matching task with two participants, they perform only at chance level (i.e., 50% correct in binary choice test) on such sentences, as they rely on guessing.

Beretta and Munn (1998) tested the TDH in contrast to the DDH (further discussed below) in a spoken-sentence-picture-matching task on passive sentences in German aphasic individuals. Their visual stimuli included pictures with reversed thematic roles as well as pictures with two agents performing the action. The results showed that in most cases, aphasic individuals chose reversible pictures instead of those with two agents. These results showed that participants did not possess *double-agent* representation. Therefore, the authors concluded that participants had not been relying on the default strategy defined by the TDH.

Caplan and colleagues (2007) further argued that if aphasics were consistently applying "guessing as last resort strategy" in deriving the meaning of the sentence, the RTs and eye-movements patterns would not have been systematically different in correctly and incorrectly responded trials (e.g., Caplan et al, 2007; Dickey et al., 2007). Caplan concludes that the at chance level performance in non-canonical sentences reflects "correct interpretation of some sentences and incorrect interpretation of others" (Caplan & Waters, 2003, p. 246). According to this view, the incorrect responses are assumed to be due to disruptions in parsing that happen only occasionally, while the correct trials are accompanied by normal parsing.

Hanne et al. (2011) applied this idea in her experiment using eye-tracking to test predictions of TDH in German. She had participants perform a sentence-picture matching task on German canonical and non-canonical sentences. Results revealed that the aphasic individuals' gaze patterns were qualitatively different in correct responses as opposed to incorrect ones. In the case of correct responses, eye-movement patterns resembled those of the control group, while in incorrect responses, eye-movements differed. Hanne and colleagues in accordance with Caplan and Waters (2003) concluded that at chance performance is not due to guessing as predicted by the *default strategy* of the TDH, but that it rather reflects different processing strategies resulting in correct or incorrect interpretations. Meyer and colleagues (2012) followed the same paradigm to investigate on-line passive sentence processing in English. They also found different patterns in correct and incorrect trials, and no agent-first bias in aphasia individuals contrary to the predictions of the TDH.

Meyer and colleagues (2012) suggest that sentence comprehension difficulties in agrammatism are due to lexical integration and/or lexical processing deficit, rather than due to a problem with syntactic representation (further discussed in the *processing accounts* section below). Moreover, the TDH assumption that the traces of movement are deleted from the grammatical representation of agrammatic individuals has been questioned in a series of experiments conducted by Choy and colleagues (Dickey et al., 2007; Thompson & Choy 2009; Choy & Thompson, 2010). Their results show that even when agrammatic participants perform at chance, they fixate at the moved constituent in on-line gap filling in eye-tracking experiments. In the case of deleted traces predicted by the TDH, such patterns would not take place. Thus, the authors argue that traces are not deleted from the grammatical representation of agrammatic individuals.

4.2.2. *The Slow Syntax Hypothesis*

An alternative to the TDH, *the Slow Syntax Hypothesis* (SSH; Piñango, 2000), holds that the comprehension difficulties of agrammatic aphasics are caused by a lack of alignment between the order of thematic roles in syntactic representation and the linear order of thematic roles in argument structure. According to this view, people with unimpaired language representation employ *semantic linking*, which establishes the correspondence between thematic roles and the linear positions. *Syntactic linking*, which ensures the correspondence between arguments and syntactic functions, is considered faster and more powerful than *semantic linking*. The SSH assumes that agrammatic aphasics process syntax slower than semantics, and when the output of these two mechanisms conflicts, the interpretation of the sentence is not clear. In such cases, aphasic individuals are reliant on guessing, who is the agent and who is the theme in passive or object-relative sentences. Thus, in sentences like *the woman was kissed by the man,* the syntactic linking guarantees that *the woman* receives an agent role and *the man* is assigned a theme role. However, semantic linking assigns an agent role to *the man* and a theme to *the woman.* Since these two interpretations are in conflict, aphasic individuals can theoretically assign both of these roles to both *the man* and *the woman* with the same likelihood. This results in aphasic individuals performing at chance in sentence-picture matching tasks. In the case of active sentences, there is no problem in interpretation because alignment of both syntactic and semantic linking is

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identical (Beretta, 2008, p. 159).

Thus, the SSH explains the difficulties with respect to somewhat faster syntactic linking that occurs in healthy speakers assuming that the syntactic process becomes slower following brain damage, which results in the comprehension deficits. This suggestion is supported by some previous findings employing the ERPs (Friederici, von Cramon, & Kotz, 1999). The SSH also has some explanatory advantage over the TDH as it can explain cross-linguistic word order variation. Korean, Japanese, or Spanish have relatively free word order in comparison to English as they allow the object to be moved to the position preceding the subject (O-S-V). Hagiwara and Caplan (1990) found at chance performance on these types of sentences in Japanese aphasic speakers. Beretta et al. (2001) reported a similar pattern in Japanese and Korean. These results are inconsistent with *the default strategy* of the TDH, which predicts below chance performance as the agent role is assigned to the linearly first NP. However, the SSH survives because it predicts at chance performance in these types of sentences and assumes *the semantic linking* to be at odds with *the syntactic linking* in such cases (Beretta, 2008, p. 160).

Nevertheless, when it comes to the passive sentences in Japanese, Korean and Spanish, these allow the *by*-phrase to be fronted to the sentence initial position. Based on the results of sentence-picture matching task in Hagiawara and Caplan (1990), and Beretta et al. (2001), agrammatic speakers of Japanese, Korean, and Spanish perform at chance in these passive sentence constructions. The results are inconsistent with the predictions of both the TDH and the SSH. According to the TDH, aphasics should have no problem in such sentences as the agent role is assigned to the *by*-phrase, and according to the SSH, the performance should be above chance as *the semantic linking* and *the syntactic linking* are fully aligned.

4.2.3. *The Double-Dependency Hypothesis*

Another alternative to the above mentioned approaches is *the Double-Dependency Hypothesis* (DDH; Manuer, Fromkin, & Cornell, 1993). As opposed to the TDH and the SSH, which are both linear models, the DDH is a hierarchical model indifferent to linearity. According to linear models, patients diagnosed with agrammatic aphasia assign thematic roles in linear order, i.e. they assign the agent role to the first relevant noun phrase (NP) in the sentence, the lower role to the second relevant NP and so on.

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The DDH assumes that the thematic roles are generated by the verb phrase. This gives the DDH a greater explanatory advantage when facing the evidence from other languages with different word order. Under the DDH, the comprehension of agrammatic aphasics should be intact when only one dependency is present in a sentence (e.g., active sentence: *the woman kisses the man*). In the case of two dependencies (e.g., passive sentence: *the man was kissed by the woman*) the comprehension is random because the relation between the NP and the trace is disrupted, and agrammatic aphasics have no choice but to guess who is doing what to whom (Beretta & Campbell, 2001). In contrast to the TDH, the DDH states that agrammatic speakers know that the verb *kiss* has two thematic roles, the agent and the theme, and they do not resort to *double-agent* representation. If an agent role has already been assigned, the other NP will automatically become a theme (Bastiaanse & Jonkers, 2012).

As mentioned above, Beretta and Munn (1998) tested both the TDH and the DDH in the spoken sentence-picture matching task with passive sentences in German. They interpreted the results as inconsistent with the TDH which would predict the *double-agent* representation. However, the data were entirely compatible with the DDH, and also with cross-linguistic word order variance observed in the studies of Beretta et al. (2001) and Hagiawara & Caplan (1990).

4.2.4. The Derived Order Problem Hypothesis

The last hypothesis we are going to discuss within the *representational accounts* section is *the Derived Order Problem Hypothesis* (DOP-H; Bastiaanse & van Zonneveld, 2005). Their hypothesis focused less on the hierarchy of the syntactic tree than the DDH, and simply predicted that sentences with derived word order are more difficult to both produce and comprehend than the sentences with basic word order. The idea is that every language has a basic word order (e.g., S-V-O in English, S-O-V in Dutch), and that all the orders different from this basic word order are derived (e.g., in passives or object relatives), and thus, more difficult to comprehend. The advantage of the DOP-H is that it addresses not only the comprehension impairment, but it also aims to explain the sentence production deficits in agrammatic aphasia.

Abuom, Shah and Bastiaanse (2013) tested the TDH and the DOP-H in bilingual Swahili-English aphasic speakers. While the TDH predicts at chance performance for

sentences with different than base word order, the DOP-H predicts below chance performance in derived word order sentences when the processing demands increase. Their results revealed that sentences in which the arguments were in derived order were harder to comprehend than sentences in which the arguments were in base word order. The authors interpreted the results as correctly accounted for by the DOP-H. The hypothesis is also consistent with other cross-linguistic evidence from Hebrew and Czech discussed in Chapter 2 (Friedman & Shapiro, 2003; Flanderková, 2015).

4.2.5. Evaluation of representational accounts

Four different hypotheses have been presented, all within the sphere of the representational accounts. The TDH has been undoubtedly one of the most influential hypotheses with an attempt to explain the difficulties in agrammatic aphasics' comprehension; however, its predictions have been repeatedly questioned. The lack of traces was disputed with respect to the recent eye-tracking studies showing on-line gap-filling (Thompson & Choy, 2009). Similarly, the *default strategy* has been questioned in some recent eye-tracking studies (Hanne et al., 2011; Meyer et al., 2012), and the *double-agent* representation is also not tenable (Beretta & Munn, 1998). Finally, cross-linguistic studies in Korean, Spanish, Japanese, and Swahili (Hagiwara & Caplan, 1990; Beretta et al., 2001; Abuom et al., 2013) revealed results inconsistent with the TDH.

The SSH is not consistent with cross-linguistic evidence when it comes to word order variety, but its advantage can be seen in its attempt to explain the difficulties with respect to somewhat faster *syntactic linking*. The question is to what extent is this temporal aspect of the SSH informative with respect to neurolinguistic theory. Beretta suggests that concentration on temporal aspects in combination with high time resolution methods in both aphasics and healthy subjects might lead to better understanding of timing in linguistic processes (Bereta, 2008, p. 162). Thus, theories referring to time are a good step forward.

The empirical coverage of the DDH is wider in comparison to the TDH and the SSH as it accounts for cross-linguistic word order variety. Concentrating on the hierarchical structure of sentences rather than on their linearity makes the DDH immune to the word order alternations in other languages. However, it does not refer to syntactic slow-down in agrammatic aphasics which is recognized in the SSH.

Finally, the DOP-H is an overarching theory attempting to explain both the production and comprehension difficulties in agrammatic aphasia. This unification attempt is probably the main contribution of this hypothesis. However, further cross-linguistic research testing the predictions of DOP-H with respect to comprehension has to be done, as the studies testing the DOP-H have been focused rather on the production impairments.

4.3. Processing deficit accounts

Alongside the *representational deficit accounts* discussed in the previous section, there is another line of research, which is referred to as the *processing deficit accounts*. Within the processing approach, poor comprehension in agrammatic aphasia is explained in terms of more general limitations in agrammatic individuals' processing capacities, while the grammatical knowledge of the patients is preserved (Patil, Hanne, Burchert, De Bleser, & Vasishth, 2015, p. 3). In other words, the grammatical impairment in agrammatism is considered to be only "an epiphenomenon of more general processing mechanisms" (De Bleser et al., 2012, p. 126). Various authors interpret the nature of the processing limitations differently. The following section discusses several distinct perspectives which assign the processing limitations to: a) *resource reduction*; b) *slow activation of syntactic information*; c) *lexical activation*; and d) *impaired lexical integration.*

4.3.1. Resource reduction

Caplan (2012) suggest that comprehension deficits in agrammatic aphasics are caused by *processing resource reductions* rather than by impaired linguistic knowledge. Caplan defines *processing resources* as certain attributes of a cognitive architecture that are necessary for cognitive operations, and can affect processing characteristics. *Processing resources* are often considered to be equivalent to working memory, speed of processing, or phonological short-term memory. Thus, they are different from computational operations or grammatical representations themselves (Caplan, 2012, p. 47). In this approach, the processing limitations in aphasic comprehension are due to the intermittent reductions in the processing capacity available for syntactic operations.

These intermittent reductions do not allow agrammatic aphasics to work with multiple syntactic operations at the same time, even though the ability to apply these syntactic operations might remain unimpaired.

Caplan et al. (2007) combined a self-paced listening paradigm with a sentence-picture matching and grammatical judgment tasks, to measure both off-line and on-line performance of aphasic individuals. The results revealed that aphasic speakers had no stable deficits towards concrete syntactic structures, but the variety of syntactic features determined the sentence processing demands. Interestingly, they found normal on-line performance associated with correct off-line responses, and contrary to this, abnormal on-line performance was found when patients provided incorrect off-line responses. These systematic differences in on-line processes are not predicted by the TDH. Caplan and colleagues interpreted the results as reflecting intermittent reductions in the processing capacity available for syntactic, interpretative, and task related operations, rather than reflecting constant damage in syntactic representation.

4.3.2. *Pathological slow-down in processing*

It is also possible that comprehension processes in agrammatism might be structurally unimpaired, but rather slowed or delayed. In this view, comprehension is affected by pathological slow-downs or delays in sentence processing. Burkardt and colleagues (2003) suggested that slowed or delayed syntactic processing affects syntactic and semantic computations of agrammatic aphasics when the order of thematic roles is reversed by syntactic movement. They concluded so based on the study using cross-modal lexical decision task in agrammatic individuals, in which they observed delays in priming of *wh*-movement structures (Burkardt, Piñango & Wong, 2003).

Another support for this view comes from the results of some recent on-line studies, which also observed slow-down or delays in agrammatic individuals comprehension compared to controls (Meyer et al., 2012; Hanne et al., 2011; Choy & Thompson, 2010). In contrast, Thompson and Choy (2009) observed no evidence for delayed processing in agrammatic aphasics in the syntactic structures involving syntactic movement. The authors concluded that sentence comprehension impairments in aphasia are unlikely to be caused by a general delay in syntactic processing.

4.3.3. Slowed lexical activation

It is also unclear whether the slow-down observed in the above mentioned on-line studies is caused solely by syntactic processing. Love and colleagues proposed *the Slow Lexical Activation Hypothesis* (SLAH; Love, Swinney, & Zurif, 2001; Love, Swinney, Walenski, & Zurif, 2008) which states that the deficits in agrammatic aphasics' comprehension are caused by slow lexical activation, rather than by slow syntactic processing. According to this view, the slowed lexical activation feeds syntactic processes too slowly, which might be one of the causes of aphasics' comprehension deficits.

Ferrill and colleagues (Ferrill, Love, Walenski, & Shapiro, 2012) used cross-modal lexical priming to investigate the time-course of lexical item processing in agrammatic aphasia. Aphasic patients showed delays in activation of lexical items which supports the SLAH. However, the authors admitted that the slowed lexical activation might contribute but does not have to be the only or the main cause of the comprehension deficits.

4.3.4. Lexical Integration Hypothesis

Meyer and colleagues proposed *the Lexical Integration Hypothesis* (LIH; Meyer et al., 2012; Mack & Thompson, 2013), which states that the deficits in agrammatic non-canonical sentence performance and associated delays in aphasics' eye-movement patterns are caused by an impaired ability to integrate lexical information into higher order representations of the preceding sentence context.

Meyer and colleagues (2012) investigated passive and active sentence processing in agrammatic aphasia using a sentence-picture matching task, and found delays in both active and correctly interpreted passive sentences. However, they do not interpret this delay as slow syntactic processing, but rather suggest that aphasics' poor comprehension is the result of impaired lexical integration and/or lexical processing. This interpretation is not necessarily exclusive with the SLAH. The results of studies on lexical ambiguity resolution, which have showed a deficit in timely selection of the appropriate meaning of ambiguous words in agrammatic patients (Hagoort, 1993; Swaab, Brown, & Hagoort, 1998), are also in support of the LIH.

4.4. Computational models of comprehension disorders

There has been also an attempt to computationally formalize cognitive principles playing role in syntactic processing. The computational models may help to establish a more transparent link between normal and impaired sentence comprehension in agrammatism. Among some existing computational models are SYNCHRON, a computational model of aphasic language breakdown (Haarmann & Kolk, 1991a), its enhanced version, CCR, a capacity constrained resource deficit model (Haarmann, Just, & Carpenter, 1997) and CBR, a cue-based retrieval model of sentence processing (Lewis & Vasishth, 2005) (for the review of these models see Patil, et al., 2015).

Computational models can be also used to assess the correlation between selected theories of aphasia and the collected data. For example, Patil and colleagues (Patil et al., 2015) used CBR to evaluate both *representational* and *processing accounts* of agrammatic aphasics. They based their evaluation on eye-tracking data collected by Hanne at al. (2011), and the results revealed that the given data are best captured by a model assuming two processing deficits: an intermittent deficiency and slowed processing, as opposed to the models based on the TDH, which fail to capture the on-line data.

As discussed in this chapter, while some authors within the sentence processing approach assign the comprehension deficits to syntactic processing, others believe the source of the comprehension impairment might be in the earlier, lexical processing stage. It is likely that impaired or delayed lexical integration or access might be combined with impaired syntactic computations or some other resource reductions, while the slow-down observed in aphasic performance might be only an epiphenomenon of these impaired mechanisms. What type of processing limitation plays a bigger role in aphasics' impaired sentence comprehension is an empirical question which needs to be addressed in future research. Computational models of both normal and impaired syntactic processing might help to evaluate how well given theories fit the empirical data.

4.5. Evaluation of representational and processing accounts

This Chapter introduced two major classes of accounts which try to theoretically approach the comprehension deficits in agrammatic aphasia: *the representational*

accounts and *the processing accounts*. The approaches within *the representational accounts* are very explicit in their statements and predictions when it comes to syntactic impairments in agrammatic comprehension. However, these linguistic approaches often overlook cognitive resources and do not address the influence of the processing capacity, or the roles of the processing load in increasingly complex sentence structures, word retrieval impairment, integration deficits or the general procedural slow-down in aphasia. They ignore all of these significant aspects of language processing and their influence on sentence comprehension. Moreover, no representational account theory considers on-line performance (Caplan et al., 2007).

The theories within the *processing approach* address all of these aspects which are overlooked by the *representational accounts,* and stress the limitations in processing capacities and their causal relationship to the impaired comprehension. From this perspective, the difficulties with increasingly complex and derived sentence structures can be accounted for as the result of an increasing computational load rather than impaired syntactic knowledge. Despite this advantage, *processing accounts* often suffer from vagueness, and lack of more explicit theoretical frameworks, as there is not a clear link established between processing capacities and their exact role in speech comprehension and syntactic processes (De Bleser et al., 2012, p. 127).

Although it could be seen that these two approaches have completely different, mutually exclusive perspectives, they are rather two sides of the same coin and stress different aspects of agrammatic comprehension deficits (De Bleser, 2012, p. 128). A truly unified theory of agrammatic impairment may need to account for both *processing* and *representational* perspectives and combine the syntactic representation of our language together with the computational demands placed on language processing in a damaged brain.

Additionally, further research in this area should make an attempt to unify both comprehension and production difficulties in agrammatism under one overarching model (see also Kolk, 1998). However, some other authors are rather skeptical towards such unification and argue that a single explanation merging all the aspects of agrammatism will never able to take into account all the observed patterns in agrammatism, as well as different degrees of severity and cross-linguistic differences (Goodglass & Menn, 1985). Despite this skeptical concern, an effort should be made to establish a connection between the *representational* and *processing* approaches, as both address different aspects present in the comprehension deficits. It seems logical that an

overarching theory capable of explaining as many aspects of agrammatism as possible is going to be not only more accurate, but also more informative to neurolinguistic theories of normal language processing and language representation in the healthy brain.

II.

The Experimental Part

5.   The passive sentence comprehension in agrammatic aphasia: Eye-tracking study in Czech[6]

This experimental study aimed to investigate canonical and non-canonical, specifically active and passive, sentence processing and comprehension in both agrammatic aphasics and healthy controls. We used the eye-tracking-while-listening paradigm together with a sentence-picture matching task to obtain both on-line eye-fixation measures and off-line accuracy rates and reaction times. Our design is largely based on Meyer et al. (2012) and Hanne et al. (2011) and further adapted to specifics of the Czech language.

5.1.   Introduction

The previous Chapters (2 and 4) already introduced and discussed the comprehension deficit of non-canonical sentence structures in agrammatism. In summary, it has been observed across many languages that individuals with agrammatic aphasia perform at chance level on semantically reversible non-canonical structures (e.g., passives, object relatives, object-cleft constructions and object questions) the interpretation of which depends on syntactic relations (e.g., Zurif & Caramazza, 1976, Thompson & Choy, 2009; Meyer et al., 2012; Bastiaanse & Edwards, 2004; Luzzatti et al., 2001; Burchert & De Bleser, 2004; Hanne et al., 2011, Yarbay al., 201; Hudousková et al., 2014). However, agrammatic aphasics' performance on canonical and irreversible non-canonical structures is above chance. So far there has been no consensus reached on the underlying cause of this deficit.

The Trace Deletion Hypothesis (TDH; Grodzinsky, 2000) proposes that the traces left after a noun phrase (NP) movement in non-canonical sentences are deleted in agrammatic aphasics' grammatical representation, which results in thematic ambiguity, and prevents the correct assignment of thematic role. According to the TDH, the agrammatic speaker applies an agent-first strategy where he assigns the agent role to the linearly first NP as well as to the *by*-phrase, which results in *double-agent representation*. Consequently, when given a picture verification task, agrammatic

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[6] The experimental study conducted by Pavlína Heinzová and Petra Chudárková that served as the basis for this chapter was part of the grant project "Use of Eye-Tracking Technology in Research on Communication Disorders", IGA_FF_2014_046.

speakers perform at chance level on non-canonical structures in contrast to canonical sentences, where the performance is above chance level (for more details regarding the TDH, see Chapter 4).

However, the TDH has been disputed based on both off-line studies (e.g., Beretta & Munn, 1998), and more recent on-line experiments using eye-tracking-while-listening (e.g., Hanne et al., 2011; Meyer et al., 2012), or self-paced-listening paradigm (e.g., Caplan et al., 2007). Interestingly, the results of these studies revealed that the participants' eye-movements qualitatively differed in correct as opposed to incorrect responses. In correct responses, eye-movement patterns resembled those of the control group, while in incorrect responses, the fixation patterns differed. These results have been interpreted as evidence that at chance performance does not reflect mere guessing as the TDH states. Instead, these authors argue that there are two different types of strategies applied by aphasics resulting in either a correct or an incorrect response.

Thompson and colleagues suggest that sentence comprehension difficulties in agrammatism are due to *lexical integration* and/or *lexical processing deficits*. This proposal stems from their previous studies focusing on *wh*-structures, object relatives and passives (Dickey et al., 2007; Thompson & Choy 2009; Choy & Thompson, 2010). All of these studies report at chance performance when it comes to sentence interpretation. However, the eye-fixations followed moved sentence constituents throughout the trials, and thus did not show signs of trace deletion as predicted by the TDH. Based on their results, Thompson and colleagues suggested that sentence comprehension deficits in agrammatism are caused by lexical integration deficits, rather than by deleted traces of movement. Following these findings, *the Lexical Integration Hypothesis* (LIH; Meyer et al., 2012) presupposes that aphasic individuals do not employ the agent-first bias characteristic for normal sentence processing observed in English (i.e., first NP is interpreted as an agent). The LIH claims that the agent first bias is absent in agrammatic aphasia because of reduced or slowed automatic lexical activation. The LIH also claims that successful lexical integration, which results in correct interpretations of passive sentences, is generally slower than unsuccessful integration leading to incorrect responses.

Moreover, based on the slow performance observed in agrammatic aphasia, Burkardt and colleagues proposed an alternative, *the Pathological Slow-Down Hypothesis* (PSDH; Burkardt et al., 2003), which suggested that the comprehension of non-canonical sentences is affected by pathological slow-downs, or delays in sentence

processing. Slowed or delayed syntactic processing affects syntactic and semantic computations of agrammatic aphasics in those syntactic structures where the order of thematic roles is reversed by syntactic movement (e.g., Haarmann & Kolk, 1991b; Piñango, 2000). This hypothesis predicts that the strategies of agrammatic aphasics are identical with healthy controls, but occur in a delayed fashion.

Regarding the comprehension deficit in Czech agrammatic speakers, one off-line study has been conducted by Hudousková et al., (2014) to test the TDH and to investigate the comprehension of reversible passive structures in Czech agrammatic individuals. Their results revealed at chance performance on passive sentence structures, which is consistent with the majority of cross-language studies showing poor performance on semantically reversible structures in agrammatism. Furthermore, Flanderková (2015) investigated grammaticality judgement and sensitivity to word order changes in agrammatic speakers. Her results revealed lower performance in agrammatic speakers in both tasks. However, no studies examining on-line performance on passives or other non-canonical structures have been conducted either on Czech aphasics or healthy speakers.

In our experiment, we aimed to investigate the active and passive reversible structures that are similar to English or German, and thus allow a cross-linguistic comparison. Differences in Czech, compared to the aforementioned languages, are a) the lack of obligatory articles, b) extra inflectional morphemes that marks the grammatical aspect in Czech, and c) the case marker at the end of the second NP (see the Figure 5.1.). The auxiliary in passive structures does not on its own indicate the passive sentence, because it can also serve, for instance, as a copula in a simple active sentence. Thus, users of Czech have to wait to hear the affix of the main verb to interpret the sentence as active or passive.

Fig. 5.1. Czech active and passive structures with their English translations. The affixes on verbs that mark the voice in Czech as well as the case agreement on NP2 are in underlined.

	Active	Passive
Czech	*Chlapec políb<u>il</u> dívk<u>u</u>.*	*Chlapec byl políb<u>en</u> dívk<u>ou</u>.*
English	*The boy kissed the girl.*	*The boy was kissed by the girl.*

Overall, the Czech language differs from English in at least two important aspects that may be relevant in the context of our experiment: 1) optional word order, and 2) the passive voice marked by an affix on the main verb. The base word order in Czech is subject-verb-object (SVO) but the Czech grammatical system offers the option of placing the theme (e.g., direct or indirect object) in the initial position. Due to this optional word order scheme, the agent in Czech is not as strictly tied to its initial sentence position as it is in English (von Stutterheim, Andermann, Carroll, Flecken, & Schmiedtová, 2012). Thus, Czech speakers may not employ any agent-first strategy typical for English speakers when performing sentence-picture matching tasks.

The morphological marker of the passive voice that appears at the end of the main verb may result in slower performance in on-line tasks, because Czech speakers have to wait until the end of the verbal phrase to decode the voice of the sentence contrary to English or German speakers that may have some temporal advantage.

In our experiment, first, we wanted to investigate the time course and eye-fixation patterns of healthy Czech adults while listening to active and passive sentences. In this respect, our study is rather exploratory, as there have not been any similar eye-tracking experiments focused on active and passive sentence comprehension in Czech. However, as discussed above, given the optional word order, we expected to observe fixation patterns which differed from the agent-first fixation patterns that would be more typical for languages with fixed word order.

Secondly, we were interested in how these patterns of normal canonical and non-canonical sentence processing differ from the eye-gaze patterns of agrammatic speakers. Based on the previous findings in English (e.g., Dickey et al., 2007) and German (e.g., Hanne et al., 2011), we expected to see similar eye-gaze patterns in both groups in correctly responded trials, but for distinct eye-gaze patterns in the incorrect ones. We also expected a general slow-down in the aphasics' performance compared to controls that could be apparent from both the reaction time analysis and the eye-tracking results.

Finally, we aimed to test the predictions of the *Trace Deletion Hypothesis* (Grodzinsky, 2000), the *Lexical Integration Hypothesis* (Meyer et al., 2012), and the *Pathological Slow-Down Hypothesis* (Burkhardt et al., 2003) in Czech aphasic speakers to bring together new cross-linguistic data, and to shed new light on the theoretical debate attempting to explain comprehension deficit in agrammatism.

5.2. Methods

5.2.1. *Participants*

Six patients with Broca's aphasia and six age-matched and education-matched healthy controls, with equal numbers of males and females in both groups, participated in the experiment. All the participants were (premorbidly) right-handed and monolingual Czech speakers with normal (or corrected-to-normal) vision and hearing. The age of the controls ranged from 28 to 70 years (mean = 42.5). The aphasic participants ranged from 28 to 69 years (mean = 52.5). Demographic data for all participants and language assessment results for aphasics are presented in Table 5.1. All the aphasics were at least six months post onset with the exception of the participant A3 that was only three months post-onset at the time of the experiment. In five cases the cause of aphasia was ischemic cerebrovascular insult, only in one case was the aphasia due to a central nervous system tumor.

Table 5.1. Demographic data of all participants and controls; the neurological and language testing data of aphasic participants. The CVI-I stands for ischemic cerebrovascular insult and the CNST stands for cerebro-nervous system tumor. In the row referring to education, the acronym HS stands for high school that equals at least 13 years of education; U stands for university that equals 16 or more years of education.

Aphasic participant	A1	A2	A3	A4	A5	A6
Age	39	29	44	68	69	66
Gender	F	F	M	M	F	M
Education (years)	HS(13)	U(16+)	U(16+)	U(16+)	U(16+)	HS(13)
Years post-onset	10	0.3	2	15	0.6	1
Cause	CVI-I	CVI-I	CNST	CVI-I	CVI-I	CVI-I
Western Aphasia Battery						
Fluency	3	3	3	2	2	5
Comprehension	6.4	7.4	4.9	6.5	7.4	7.1
Repetition	3.3	4.8	4	2.6	6.8	4.5
Naming	4.7	5.9	5.3	2.9	4.4	6.1
Aphasia quotient	40.8	52.3	40.3	32	43.2	55.4
Northwestern Assessment of Verbs and Sentences (%)						
Verb comprehension	85.71	100	85.71	66.67	95.24	85.71
Active sentence comprehension	100	100	100	40	100	100
Passive sentence comprehension	40	60	20	80	100	0

Control participant	C1	C2	C3	C4	C5	C6
Age	41	41	28	46	70	29
Gender	M	M	F	F	F	M
Education	U(16+)	U(16+)	U(16+)	U(16+)	HS(13)	U(16+)

The participants were classified as having Broca's aphasia using the *Western Aphasia Battery* (WAB; Kertesz, 1982), with mild to moderate severity (mean Aphasia Quotient = 44.0, range = 32-55.4), the fluency scores from 2 to 5, relatively spared auditory comprehension (range = 4.9-7.4) and naming (range = 2.9-6.1).[7] For all participants, non-fluent and telegraphic speech with grammatical errors was characteristic. To assess agrammatism, we used a partially translated experimental version of the *Northwestern Assessment of Verbs and Sentences* (NAVS; Thompson, 2011). Using this battery, we tested the sentence comprehension ability in a sentence-picture matching task with semantically reversible sentences and two-argument, transitive verbs. Participants performed well on canonical sentences, but showed decreased or at chance performance on non-canonical sentences, as predicted by the TDH. Only participant A6 performed better on non-canonical sentences than on canonical ones, however, during the experiment, this patient was not performing as an outlier and therefore was included in the analysis. Pre-testing also showed that all participants were able to read simple words without any difficulties.

5.2.2. *Materials*

We selected 40 two-argument frequently used verbs from the SYN corpus of Czech language (see Appendix I). For each verb, four types of sentences were created: active, passive, subject cleft (SC), and object cleft (OC). Active and passive sentences were both used as experimental conditions, while SC and OC sentences served as fillers. The sentences within each of these conditions contained the same number of words and were counterbalanced on gender to avoid possible predictability. All the sentences were recorded digitally, with a normal speech rate by a male native Czech speaker, and the voice volume was normalized using Audacity (version 2.0.6; Audacity Team, 2015).

The sentences were organized into two stimulus lists. Each list included a total of 80 trials, consisting of 20 trials of each sentence type. The first half of each list included all verbs – one sentence for each verb. In the second half, each verb was repeated within a different type of sentence structure. If the verbs were used in the testing condition in the first part of the list, they appeared in the filler type of sentence in the second part of

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[7] The WAB battery has not been standardized for Czech. But due to lack of other classification tools, we were forced to use the unstandardized, translated version.

the list, and vice versa. Thus, equal numbers of canonical and non-canonical constructions were used in each stimulus list, and each verb appeared in both the active and passive forms across the whole experiment, as well as in both SC and OC type filler.

For each verb, two simple black-and-white line drawings were created (Fig. 5.2.). In one picture, the first noun of the sentence was depicted as an agent (*Chlapec maluje dívku / The boy is painting the girl*), whereas in the second picture it was depicted as a patient (*Chlapec je malován dívkou / The boy is being painted by the girl*). In the presentation, the target pictures appeared evenly on both the left and right side of the screen throughout the whole experiment in order to avoid predictability. All the pictures were evaluated by four healthy volunteers and the problematic items were discarded and replaced to avoid ambiguity in the drawings.

Fig. 5.2. The example of picture stimuli from a testing trial. The verb depicted here is *malovat* (to paint).
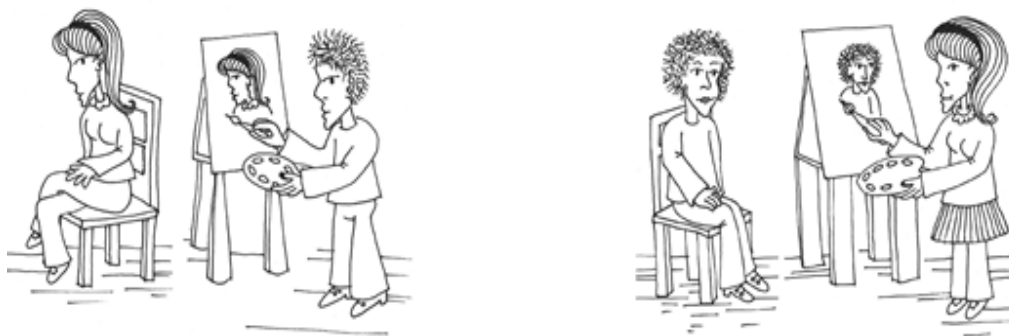
5.2.3. Apparatus

A portable Eye Tribe Tracker was used with a sampling rate of 60 Hz. The visual stimuli were presented using OGAMA software (version 5.0.5614; Voßkühler, 2015) on the screen of the digital monitor with resolution 1024x768 placed approximately 50 cm from the participant's eyes. There were two speakers at each side of the monitor screen presenting the auditory stimuli.

5.2.4. Procedure

Prior to the experiment, each participant was familiarized with the visual stimuli. For each verb, two relevant drawings, along with the corresponding written form of the

verb, were printed on an A4 paper. All the printed pictures were collected in a folder. Each participant was asked to go through the drawings, read the verb silently, and report possible difficulties with the item. During this presentation, participants experienced no problems understanding the pictures or words.

Following the visual stimuli presentation, participants were asked to sit comfortably in front of the computer screen, and the examiner provided them with the instructions concerning the experiment: at the beginning of each trial, a fixation cross would appear for 3 seconds and they should direct their eye gaze at it. Then, they would see two drawings and hear a sentence, and use either the right or left keyboard arrow to indicate which drawing corresponds to the sentence. After clicking on the key, the experiment would continue with next trial.

Following the instruction part, the participants were calibrated and the experiment began. At the beginning of each trial, a fixation cross appeared for 3 s on the screen followed by two pictures. With a delay of 500 ms, the auditory stimulus started (Fig. 5.3.). The picture stayed on the screen until participants pressed a corresponding key, which would start the next trial. The whole experiment was divided into 10 blocks of 16 trials, and in between each block participants were given a break after which they were recalibrated. The whole eye-tracking experiment, including the breaks, took approximately 40 minutes. After the experiment, all the participant were given a small financial reward.

Fig. 5.3. Illustration of the experimental paradigm; the fixation cross appeared for 3 s followed by the visual stimuli (both the target picture on one side and the distractor on the other side); 500 ms later the auditory stimuli (sentence in one of the conditions) was presented.
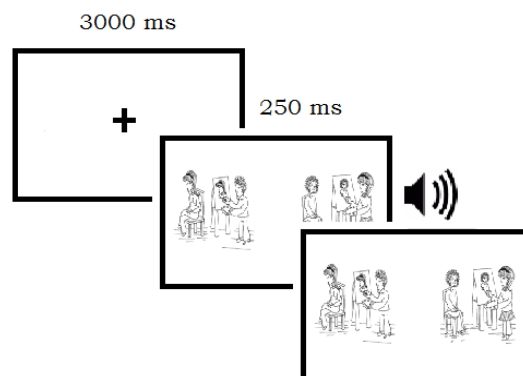
5.3. Data analysis

For each passive and active sentence, three regions of interest were defined: R1 - Noun 1 (from the onset of the first noun to the onset of the auxiliary verb), R2 - Verb (from the onset of the auxiliary verb to onset of the second noun), R3 - Noun 2 (from the onset of the second noun to the time point of 2 s).[8] Because of the delay of programming and the execution of eye movements, each region of interest began and ended 200 ms later than the associated linguistic stimulus (Altman & Kamide, 2004). Durations of the time windows were calculated for each sentence separately using the Audacity (Version 2.0.6.; Audacity Team, 2015).

Table 5.2. The regions of interest.

	Region 1 (N1)	Region 2 (Verb)	Region 3 (N2)
Active	*Muž*	*informoval*	*policistu.*
	The man	*informed*	*the policeman.*
Passive	*Muž*	*byl informován*	*policistou.*
	The man	*was informed*	*by the policeman.*

We calculated the proportion of fixations, where a fixation was considered as an eye gaze remaining in the same position for at least 100 ms. Within each region of interest, the proportions of target vs. distractor fixations were calculated. Then, the mean target advantage scores were obtained by subtracting the mean distractor fixations from the mean target fixations. These target advantage scores were used in one sample *t-test* with the alpha value 0.05. The comparison value 0.5 was used as equal to at chance performance in the statistical tests.

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[8] We calculated the fixations in the 3rd region only up to the length of 2 s instead of the full trial length in order to exclude the erroneous fixations observed after the duration of 2 s across many participants.

5.4. Predictions

We expected high accuracy rates in both active and passive condition in the control group whereas aphasics were expected to perform with less accuracy in active condition and only at chance level in the passive condition as observed in previous studies (e.g., Zurif & Caramazza, 1976; Hudrousková et al., 2014). Following Hanne et al. (2011) we also expected the aphasics' reaction times to be significantly longer in both conditions compared to the controls, but with a greater difference in passives, reflecting the severe non-canonical sentence impairment in aphasia. Furthermore, we expected to find the effect of response accuracy on the reaction times. Based on the previous studies, the incorrect trials could either take longer compared to the correct trials, reflecting the higher processing load on impaired sentence comprehension (Hanne et al., 2011) or conversely, the RTs could be shorter, which would be consistent with the results of Meyer et al. (2012), suggesting that successful lexical integration, leading to correct responses, is generally slower than unsuccessful lexical integration, that leads to incorrect responses.

In terms of controls' eye-gaze patterns, we expected either minor or no agent-first strategy in the active condition, and no agent-first bias in the passive condition, due to the rather free word order of Czech language. If the controls employed the agent-first strategy, we would expect to observe this pattern as soon as they heard the first noun (i.e., during the R1). In the active condition, agent-first strategy would be manifested as a positive target advantage (i.e., successfully employed agent first strategy), while in the passive condition we would expect to observe negative target advantage reflecting agent-first bias (i.e., unsuccessful agent first strategy). No agent-first strategy would be manifested as at chance fixations towards both target and distractor in the first sentence region.

We were also interested in whether Czech speakers would exhibit early fixations on the correct picture immediately upon hearing the verb in accordance with Meyer et al. (2012). Hanne and colleagues (Hanne et al. 2011) also observed this early advantage, but only in the passive condition, whereas the target advantage emerge later in the final sentence region in the active condition. The positive target advantage right upon hearing the verb in the R2 for the healthy participants would imply rapid lexical integration. The same pattern used in aphasics would imply similar rapid integration and processing. On the contrary, delayed, weaker or absent patterns in aphasics would

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indicate disrupted or delayed lexical integration. Meyer and colleagues observed a delayed pattern of eye-fixations in aphasics relative to controls, with a target picture advantage occurring only in the sentence-final region in the correctly responded trials. Observing similar quantitative differences (i.e., differences among the time course of sentence processing) in the agrammatic group would support the hypothetical suggestions that agrammatic aphasia is associated with slowed lexical integration and/or slowed syntactic processing (Meyer et al., 2012; Burkhardt et al., 2003).

Finally, based on previous research (Dickey et al., 2007; Hanne et al., 2011) we expected aphasics' eye-gaze patterns in the passive condition to qualitatively (i.e., visual attention allocated in the same areas of the picture) resemble controls in correctly responded trials but differ in the incorrect trials (i.e., the locations of visual attention throughout the trial would differ in both groups). Such an observation would imply that aphasics use two sets of strategies leading to either correct or incorrect passive sentence interpretation, and that they do not simply diverge to guessing as predicted by the TDH. However, at chance looks towards the target and distractor in both correct and incorrect passive sentence trials would be consistent with the TDH proposal that chance-performance reflects aphasics' guessing.

5.5.   Results

5.5.1. Behavioral accuracy

The control group had no difficulties in sentence comprehension in active or passive condition. The mean accuracy rate (proportion of correct responses) was 0.98 (SE = 0.01) in the active condition, and 0.98 (SE = 0.01) in the passive condition. Aphasic participants demonstrated reduced accuracy for both active and passive sentences as expected. The mean sentence accuracy rate was 0.82 (SE = 0.04) in the active and 0.49 (SE = 0.1) in the passive condition. Aphasic participants performed significantly better than chance in active sentences ($t(5) = 7.37, = p < 0.001$), but their performance was not significantly different from chance in the passive condition ($t(5) = .08, p > 0.10$). We also tested the difference between the two conditions in the aphasic group, and the performance on passive sentence comprehension was revealed to be significantly poorer than the performance in the active condition ($t(5) = 3.46, p = 0.01$).

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5.5.2. The RTs

The average reaction times were calculated in each condition for each subject and group (see Fig 5.4.). The mean RT for the control group was 3.03 s (SE = 0.06) in the active condition, and 3.24 s (SE = 0.05) in the passive condition. Aphasics were slower in both conditions, performing with the mean RT = 4.65 s (SE = 0.1) in active and 5.40 s (SE = 0.2) in passive condition. Thus, the aphasics were on average 1.60 s slower in active trials, and 2.16 s slower in passive trials. We also tested the mean difference between the two groups and conditions in a two sample *t*-test with the alpha value of 0.05 and obtained a significant difference between the two groups in the active ($t(5) = 4.74$, $p = 0.003$) and passive condition ($t(5) = 4.66$, $p = 0.003$). This reaction time comparison indicates that aphasics are generally slower when performing sentence-picture matching tasks compared to the controls.

Fig. 5.4. The mean reaction times calculated for aphasics and controls in both active and passive condition. The asterisks denotes the significant difference.
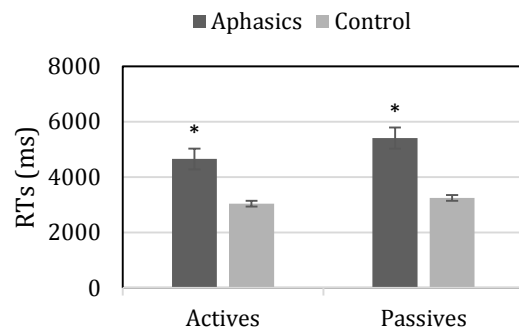
Fig. 5.5. The mean reaction times in the aphasic group as a function of accuracy (correct, incorrect) calculated for both active and passive condition. The asterisks denotes the significant difference.
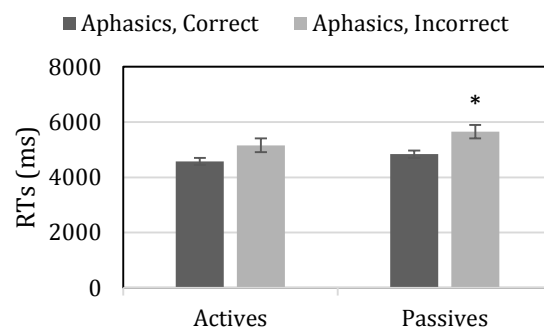
5.5.3. The RTs as a function of accuracy

In order to obtain the effect of accuracy on the reaction time of aphasic participants, we calculated the mean reaction time for correctly and incorrectly responded trials in both active and passive condition for each participant (see Fig. 5.5.). These mean reaction time values were used in a paired sample *t*-test with the alpha value of 0.05 to calculate the difference between active correctly vs. active incorrectly responded trials, and passive correctly vs. passive incorrectly responded trials. The results revealed no significant difference between active correct and active incorrect trials, but we found a significant difference in the passive correct vs. passive incorrect trials in aphasic

participants ($t(5) = 4.95$, $p = 0.004$). These results indicate a higher processing load on the impaired passive sentence comprehension in aphasics.

5.5.4. Eye-tracking results

The mean target picture fixation scores for each participant and group were calculated. The obtained means were tested against the value 0.5 which represented at chance performance with at chance looks at either positive target or negative target picture, where the value 1 represented 100% positive target advantage and the value 0 represented 100% negative target advantage (see Fig. 5.6)

Surprisingly, the control group showed negative target advantage in the active condition during the R1 ($t(5) = -2,91$, $p = 0.01$), followed by at chance looks during the R2 and finally, the positive target advantage emerged in the R3 ($t(5) = 14.63$, $p < 0.001$). In the passive condition, we observed positive target advantage during the R1 ($t(5) = 2.31$, $p = 0.03$), at chance looks in the R2 and the significant positive target advantage that emerged within the region 3 ($t(5) = 8.72$, $p < 0.001$). The eye-fixation patterns in both conditions within the R1 were very surprising, as we expected the opposite behavior based on the results of Meyer et al., (2012). The opposite pattern may be caused by either the relatively free word order in Czech, or by the tendency of Czech speakers to focus on the theme rather than on the subject of the action. This issue will be further addressed in the discussion section.

The aphasics, similar to the controls, showed negative target advantage in the active condition in the R1 ($t(5) = -2,77$, $p = 0.01$), followed by at chance fixations at both target and distractor observed in the R2. In the R3, positive target advantage emerged ($t(5) = 2.64$, $p = 0.03$). In the passive condition, there was no target advantage observed in regions 1, 2, or 3, and aphasics were looking at both pictures with at chance level, which is consistent with aphasics' behavioral performance and the previous studies (for the t results and p values, see Tab. 5.3 in the Appendix II).

Fig. 5.6. Mean target advantage calculated for both controls and aphasics by condition (active, passive) and region (R1, R2, R3). The asterisks denotes the significant positive or negative target advantage.
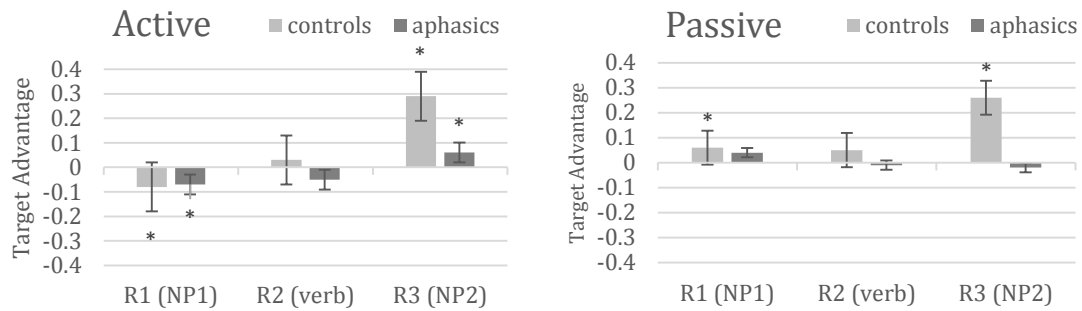
5.5.5. Fixation as a function of accuracy

In order to obtain the eye-fixations as a function of behavioral accuracy, we calculated the mean target advantages of the eye-fixations for correctly and incorrectly responded trials for each aphasic participant and condition (see Fig. 5.7 and Appendix II, Tab. 5.8).

In the active, correctly responded trials we observed at chance fixations at both target and distractor pictures during the R1 with a marginal trend for negative target advantage, that did not reach significance ($t(5) = -1.87$, $p = 0.06$), and that was not observed when calculating the correct and incorrect trials together. These eye-gaze patterns resembled the negative target advantage in the active condition in the control group, and it seems that both controls and aphasics may be using the same strategies when interpreting actives. At chance performance throughout the R2 was observed; and in the R3, the significant positive target advantage emerged ($t(5) = 3.05$, $p = 0.01$).

For the active but incorrectly responded trials, we obtained negative target advantage in the R1 ($t(5) = -2.08$, $p = 0.04$), that was also not apparent when calculating the correct and incorrect responses together. This again suggests similar strategies in aphasics and healthy controls when interpreting actives. During the R2, we observed the same negative trend that also did not reach significance due to high data variability ($t(5) = -0.9$, $p = 0.1$). The at chance performance throughout the R2 and the R3 with no significant negative or positive target advantage is consistent with their behavioral performance.

In the passive, correctly responded trials, we observed at chance fixations with no significant target preference in the R1 and R2. However, the aphasics showed positive target advantage in the R3 ($t(5) = 2.54$, $p = 0.02$). This positive target advantage

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was not apparent when calculating the correct and incorrect trials together, and suggests that aphasics do not simply guess when interpreting the passive sentences. Instead, they seem to apply different strategies that result in either successful or unsuccessful interpretations of passives.

In the passive, incorrectly responded trials, we observed at chance looks in the R1 and R2, followed by negative target advantage in the R3 ($t(5) = -10.77$, $p < 0.001$), corresponding to the behavioral performance, and reflecting the incorrect sentence interpretation. The positive and negative target advantage was not apparent when calculating the correct and incorrect trials together, and signifies that aphasics do not simply guess when interpreting the passives as the TDH predicts. Instead, aphasics may attempt to parse the sentence as passive, but in doing so they might be often unsuccessful (the t values and p values listed in the Tab. 5.4 in the Appendix II).

Fig. 5.7. The Mean target advantages calculated for aphasics by behavioral accuracy (correct, incorrect), condition (active, passive) and sentence region (R1= 1st noun, R2 = verb, R3 = 2nd noun). The asterisks denotes the significant positive or negative target advantage.
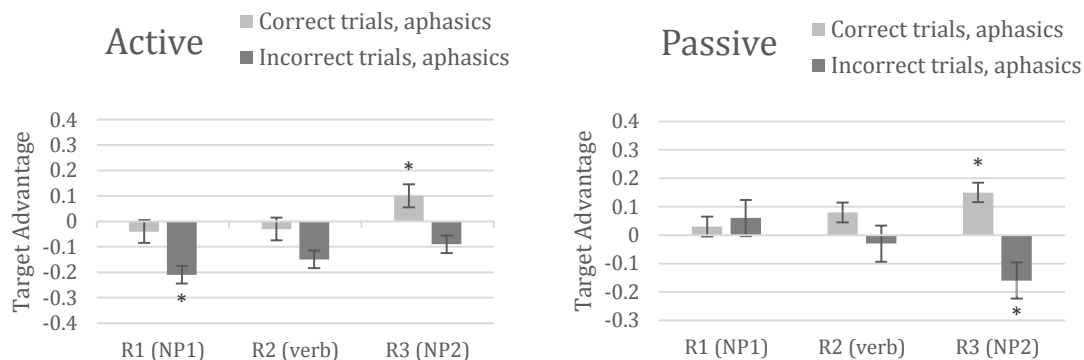
5.5.6. Summary of the results

To sum-up our results, the controls' accuracy rates were excellent in both the active and passive condition, contrary to the aphasics who performed with difficulties in actives and only at chance in passives. The reaction times analysis showed that aphasics' responses took overall longer in both conditions compared to controls, with a more prominent difference observed in the passive condition. The analysis of the effect of accuracy on the RTs' within aphasics' revealed significantly longer RTs' in incorrectly responded passives compared to correctly responded passives. No such difference was found in the active condition. The eye-tracking data revealed that

healthy controls tend to fixate on the negative target picture at the sentence onset, followed by at chance looks at both distractor and target, with positive target advantage emerging in the final sentence region. Aphasics' eye-gaze patterns in correctly responded trials resembled those of the controls, while the fixation patterns in incorrect trials were qualitatively different from the sentence onset. In the active incorrectly responded trials, aphasics showed negative target advantage and were unable to reanalyze the interpretation throughout the sentence. In the passive condition, we observed at chance looks at both target and distractor with significant negative target advantage arising towards the sentence final region.

5.6. Discussion

The present study investigated aphasics' and age-matched controls' accuracy, reaction times and eye-fixation patterns while performing a sentence-picture matching task. In this task, participants were shown pairs of pictures with reversed thematic roles, and asked to match the aurally presented active and passive sentences with the corresponding pictures.

The controls' accuracy rates were excellent in both active and passive condition. However, aphasics performed above chance on actives, and only at chance level on passives. These results are in accordance with our predictions and consistent with the previous studies (e.g., Zurif & Caramazza, 1976; Grodzinsky et al., 1999). The comparison of reaction times among groups revealed significantly slower performance in aphasics in both active and passive condition compared to controls, and this difference in RTs was more prominent when comparing passives in the two groups. These results may indicate either slower syntactic processing (Burkhardt et al., 2003) and/or impaired lexical integration (Meyer et al., 2012) of both active and passive sentences, though having a greater effect on the non-canonical passives. Since the task used in our experiment involves both lexical and syntactic processes, it is not possible to underpin the exact source of the slow-down. Both abovementioned hypotheses could be further tested in future experiments designed to disentangle the slowed lexical integration slowed syntactic processing.

When comparing the RTs within the aphasic group as a function of behavioral accuracy, we observed no significant difference between correctly and incorrectly

responded trials in the active condition, which means that the time course of mechanisms applied in both successfully and unsuccessfully interpreted sentences were alike. However, the RTs of aphasics in incorrectly responded passive sentences were significantly longer than the RTs in correctly interpreted passive trials. This difference indicates a higher processing load on the impaired passive sentence comprehension in aphasics, which is consistent with the results of Hanne et al. (2011). However, these results do not support the proposal of Meyer and colleagues (2012) that strategies resulting in correctly interpreted sentences take generally longer. The difference in RTs as a function of behavioral accuracy is also in contradiction with the TDH predictions. If the participants were simply guessing when interpreting passives as the TDH predicts, the latencies should not differ.

When analyzing the eye-tracking data in the control group, we found an early negative target advantage in the first analyzed region (R1) in the active condition, and an early positive target advantage in the same region in the passive condition. Similar patterns were observed in the aphasic group in the active condition. These findings are inconsistent with the previous studies in English reporting agent-first strategy and agent-first bias in healthy participants (Meyer et al., 2012). The agent first strategy is the tendency to interpret the first noun phrase of the sentence as an agent simply because the agent usually holds linearly first position in the sentence (with the exception of non-canoncial structures). However, this rule applies for languages with agent-action-patient thematic role order (e.g., English). Languages with grammatical systems lacking a close relationship between agent role and initial position in the sentence (e.g., German or Czech) offer the option of placing the theme in the initial position (von Stutterheim et al., 2012). Thus, employing syntactically based strategies to interpret such a sentence is not as essential in Czech or German as it is in English. This is likely the reason why we did not observe any signs of an agent-first strategy in the eye-tracking patterns of Czech aphasics and controls. It also implies that the TDH operating with this type of strategy does not explain the behavior in languages with rather free word order.

Interestingly, in the same region (R1) we observed a tendency in both controls and aphasics (though only nearly significant in aphasics) to fixate on the picture in which the presented noun was the patient. These eye-tracking patterns differ not only from the English results but also from the findings in German (Hanne et al., 2011). Based on the previous cross-linguistic studies (for review see von Stutterhein et al.,

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2012), we argue that grammatical differences of Czech may lead to different categorization of events that affected the eye-gaze patterns in the sentence-picture matching task we have observed. Evidence from previous cross-linguistic studies suggests that speakers of different languages attend to the events in different manners, and these differences arise from the differential grammatical devices that place distinct constraints on the categorization of these events. For example, speakers of German, Czech and Greek are goal-oriented (i.e., they tend to focus at the endpoint of the event or at the theme of the event first) while English or Russian speakers do so to a lesser extent (Schmiedtová & Sahonenko, 2008; Papafragou, Hulbert, & Trueswell 2008; von Stutterheim et al. 2012; Carroll, & von Stutterheim, 2010). This may arise, as von Stutterheim and colleagues argue, from the cross-linguistic differences in grammatical aspect that affect the event conceptualization and distribution of attention when talking about or viewing motion events (von Stutterheim et al., 2012). Furthermore, Papafragou suggests that language is a system of representing, organizing, and tracking events, which may give rise to cross-linguistic differences in attention allocation while event details are perceived and stored to memory (Papafragou, 2015).

Based on these assumptions and in accordance with our eye-gaze data, we propose that Czech speakers may employ the *patient-first strategy* which, as we hypothesize, is a tendency to initially focus on the patient (or a theme) of the picture rather than on the agent performing the ongoing action (as would be typical in English). We suggest that the *patient-first strategy* applied by Czech speakers may be further tested in both the production and comprehension modality employing eye-tracking method together with some type of visual stimuli (e.g., sentence-picture matching or motion events description) where the fixations at specific areas referring to the patient, agent and action could be carefully analyzed (similarly to e.g., Paparfragou et al., 2008).

Moving beyond the sentence onset, we observed no target fixations immediately upon hearing the verb in healthy controls. Instead, the positive target advantage only arose in the sentence-final region, in contrast to the work of Meyer et al. (2012) that offered evidence for early positive target advantage in healthy speakers. This relatively late positive target advantage in Czech speakers may be related to the morphological system of Czech language. In order to interpret the sentence as active or passive, Czech speakers have to hear the affix of the verb. This may be the reason why Czechs fixate on the target relatively slower compared to other cross-linguistic data.

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Regarding the time course of aphasics' sentence processing, even though our RTs support the PSDH (Burkhardt et al., 2003), the slowed eye-gaze patterns were not apparent when comparing the aphasics to the controls. Both groups showed positive target advantage relatively late. However, we cannot exclude the option that aphasics' target advantage in correctly responded trials did arise later, and that we were unable to detect it in our analysis that only consisted of 3 regions of interest. We suggest that the late positive target emergence in aphasics could be tested by separating the sentences into more regions corresponding to the morphological rather than lexical units of the sentence. Such detailed analysis could bring new light on the time course of canonical and non-canonical sentence processing in both healthy and aphasic individuals.

The analysis of aphasics' eye-gaze patterns revealed qualitatively similar fixation strategies in the active condition, but different patterns in the passive condition when compared to controls. These results offer a view that aphasics use similar strategies in canonical sentences compared to controls, but resort to somewhat abnormal mechanisms, when encountered with non-canonical sentences. However, the analysis of the eye-gaze patterns as a function of response accuracy brought more nuanced results. Whereas, the correct trials of aphasics qualitatively resembled the eye-gaze patterns of controls, the incorrectly responded trials were distinct from the beginning of the sentence onwards. Thus, it is likely, that different mechanisms underlie correctly and incorrectly interpreted sentences. In the active condition, incorrectly responded trials, we observed significant bias towards distractor from the sentence onset. Upon this bias, aphasics were unable to change their prior interpretation which resulted in incorrect response. In the passive condition, incorrectly responded trials, aphasics' fixations were focused on both target and distractor throughout the whole sentence until the final sentence region where they resorted to the negative sentence interpretation. Such eye-gaze patterns are inconsistent with the TDH that predicts unitary at chance looks regardless of whether the final response is correct or incorrect.

To conclude, our results contribute to the understanding of sentence processing of canonical and non-canonical sentences in aphasics and healthy controls at least in 3 aspects. First, it brings new insight into the time course and eye-fixation patterns of healthy Czech adults' sentence processing of both canonical and non-canonical sentence structures. Second, it reveals how these patterns in healthy Czech speakers differ from the eye-gaze patterns and the time course of agrammatic speakers' sentence

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processing. Finally, our results contribute to the theoretical debate attempting to explain non-canonical sentence comprehension deficits in agrammatism bringing new evidence against the TDH, and partially also against the LIH. The results confirmed the predictions of the PSDH, that assume the agrammatic comprehension deficits to be qualitatively similar to controls, but pathologically slowed, and hence, quantitatively different in agrammatism. Even though we did not aim to test the *Derived Order Problem Hypothesis* (DOP-H) discussed in the Chapter 4, this hypothesis may also be potentially consistent with our data. But we would need to further test and compare the performance and eye-gaze patterns on active non-canonical vs. active canonical sentences to test its explicit predictions.

For further research, we would like to first stress the importance of analyzing the correct and incorrect trials separately (in agreement with Caplan, 2007, Hanne et al., 2011 and Meyer et al., 2012). Second, we would like to encourage cross-linguistic research of agrammatism as the research biased towards few languages only may mask the true nature of underlying comprehension deficit that aphasics suffer from.

Conclusion

Firstly, this thesis aimed to introduce the syndromes of agrammatic aphasia; its neurological underpinnings; the main approaches to its research; and the major issues and controversies related to the study of agrammatism. From this general introductory discussion provided in Chapter 1, the thesis proceeded to a more concrete description of the symptoms of agrammatism.

Thus, Chapter 2 discussed the main symptoms in both comprehension and production modalities and their cross-linguistic alternatives. As demonstrated in Chapter 2, agrammatic symptoms include problems in production of bound morphemes, the omission of functional words, and non-canonical sentence comprehension deficits. However, concrete patterns may vary cross-linguistically. Special attention was given to the agrammatic manifestations present in Czech. It has been shown that Czech patients tend to erroneously substitute bound morphemes, omit the functional words in their speech, and perform at chance or slightly above chance on sentences with non-canonical word order in both grammatical judgement and sentence-picture matching tasks.

Chapter 3 introduced and evaluated different methods, paradigms and tasks traditionally applied in the research of agrammatism. These methods were classified according to their capabilities to access automatized language processes into two categories: *on-line* and *off-line*. Consequently, this chapter aimed to argue the importance of combining both off-line and on-line paradigms so as to access the automatic cognitive processes.

Chapter 4 served as the review of the most well-known theoretical approaches in the comprehension modality of agrammatism. The chapter was divided according to the means by which these approaches attempt to explain the comprehension deficits in two main groups: *representational deficit accounts* and *processing deficit accounts*. The selected hypotheses within these accounts were discussed together with the current empirical studies providing evidence for their support. This chapter also argued that the accounts from these seemingly contradictory standpoints should optimally be combined into one overarching type of theory explaining the agrammatic deficits across all modalities with respect to both language representation and processing.

The experimental part of the thesis, that is Chapter 5, built upon the preceding theoretical discussion and aimed to investigate the comprehension of active and passive

sentences in Czech agrammatic speakers and healthy controls. This experiment employed the eye-tracking-while-listening paradigm combined with a sentence-picture matching task to investigate the automatic eye-gaze patterns of aphasics in relation to the accuracy and reaction times measured during the task. In the analysis, we compared the aphasics to the control group to observe the differences among both groups with an attempt to infer the causes of the agrammatic comprehension deficits. We also compared the eye-gaze patterns and reaction times as a function of behavioral accuracy. The results revealed relatively similar eye-gaze patterns in both aphasics and controls in the correctly responded trials but differential patterns in the incorrectly responded trials, suggesting that erroneous strategies are inconsistently applied by aphasics when interpreting passive sentences. The same was the case for incorrectly responded active sentences. Our results neither corroborate the *Trace Deletion Hypothesis* nor they directly support the *Lexical Integration Hypothesis*. However, taking into consideration the slow-down observed in the reaction time analysis of both groups, our results are consistent with the *Pathological Slow-Down Hypothesis*. Nevertheless, further testing needs to be done to infer whether the syntactic, morpho-syntactic or lexical processes are more impaired in agrammatic speakers.

Future research in this area should attempt to use on-line methods in the investigation of comprehension deficits, because the automatic processing strategies that appear to be disrupted in agrammatism cannot be accessed by purely off-line methods. Another recommendation refers to the importance of analyzing the on-line behavior of participants separately for correct and incorrect answers (in agreement with Caplan, 2007, Hanne et al., 2011 and Meyer et al., 2012). Moreover, a combination of different methods and experimental paradigms, for example using the ERPs to further investigate the time-course and delays in aphasic non-canonical sentence processing, can reveal some novel findings that can inform the current research or even change its direction. And finally, conducting further cross-linguistic studies is of a crucial importance because agrammatic symptoms are manifested differently depending on the grammatical structure of any given language. Thus, to accurately describe the deficits in agrammatism and find its adequate correlates and causes, we need to look at a wide variety of languages and study both similarities and differences in the symptoms of agrammatism among these languages. The theories derived from comparative cross-linguistic studies will allow us to point to the universal mechanisms that constitute the source of these deficits. Only if these core sources are identified and tapped into can

the performance of the agrammatic aphasics be properly treated and improved. Regarding Czech language, there is not only a lack of studies focusing on aphasia and agrammatism, but also there are almost no studies investigating on-line sentence processing in healthy Czech speakers. Such primary research is crucial as it provides data on healthy processing patterns, which can serve as the basis for predictions on impaired sentence processing. The research of normal language processing is an indispensable prerequisite for understanding language deficits of any kind, including agrammatism.

The issues discussed in the thesis indicate that agrammatism is a complex syndrome that does not have a unitary explanation on either a linguistic or a neurological explanatory level. Some authors argue that such a unitary explanation of all the deficits of agrammatism is illusory (Thomspon & Bastiaanse, 2012, p. 12). Research of agrammatism may as well lead to several explanations that could further apportion agrammatism into several variants. But regardless of what directions this research will take in the future, it is already apparent that due to the increasing amount of cardiovascular diseases, including stroke, the study of agrammatic aphasia will be of increasing importance. The communication problems associated with agrammatism have a severe impact on the social and working lives of the people afflicted with this handicap and therefore, from the perspective of the psychological health and economic well-being of the population, this issue should be given appropriate attention. Apart from the direct benefits of agrammatism research in treatment and therapy, there is also an enormous potential to study damage to language-related areas of the brain and their functional correlates. Such research can inform the normal models of language representation and processing and give us a better insight into the cerebral organization of language and a better understanding of language related processes.

Appendices

Appendix I. Verbal stimuli.

Verb (trs.)	Freq. (trs.)	Active sentence (trs.)	Passive sentence (trs.)
1. chytat (catch)	**65956**	**Chlapec chytá dívku.** *The boy is catching the girl.*	**Chlapec je chytán dívkou.** */ is being catched by the girl*
2. volat (call)	**176771**	**Dívka volá chlapce.** *The girl is calling the boy.*	**Dívka je volána chlapcem.** */ is being called by the boy.*
3. malovat (paint)	**49529**	**Chlapec maluje dívku.** *The boy is painting the girl.*	**Chlapec je malován dívkou.** */ is being painted by the girl.*
4. pozorovat (observe)	**88348**	**Muž pozoruje chlapce.** *The man observes the boy.*	**Muž je pozorován chlapcem.** */ is being obs. by the boy.*
5. otrávit (poison)	**15923**	**Žena otrávila muže.** *The woman poisoned the man.*	**Žena byla otrávena mužem.** */ was poisoned by the man.*
6. hladit (stroke)	**9938**	**Maminka hladí dceru.** *The mother strokes the daughter.*	**Maminka je hlazena dcerou.** */ is being stroked by the daughter.*
7. urazit (insult)	**29492**	**Chlapec urazil dívku.** *The boy insulted the girl.*	**Chlapce byl uražen dívkou.** */ was insulted by the girl.*
8. sledovat (follow)	**383755**	**Detektiv sleduje zloděje.** *The detective followed the thief.*	**Detektiv je sledován zlodějem.** */ was followed by the thief.*
9. obsloužit (serve)	**6293**	**Sluha obsloužil krále.** *The servant served the king.*	**Sluha byl obsloužen králem.** */ was served by the king.*
10. napadnout (attack)	**239085**	**Medvěd napadl myslivce.** *The bear attacked the hunter.*	**Medvěd byl napaden myslivcem.** */ was attacked by the hunter.*
11. zabít (kill)	**163229**	**Muž zabil ženu.** *The man killed the woman.*	**Byl to muž, kterého žena zabila.** */ was killed by the woman.*
12. lechtat (tickle)	**824**	**Chlapec lechtá dívku.** *The boy is tickling the girl.*	**Chlapec je lechtán dívkou.** */ is being tickled by the girl.*
13. česat (comb)	**3151**	**Maminka češe dceru.** *The mother combs the girl.*	**Maminka je česána dcerou.** */ is being combed by the girl.*
14. rozplakat (make cry)	**7879**	**Chlapec rozplakal dívku.** *The boy made the girl cry.*	**Chlapec byl rozplakán dívkou.** */ was made to cry by the girl.*
15. kopat (kick)	**48340**	**Dívka kope chlapce.** *The girl is kicking the boy*	**Dívka je kopána chlapcem.** */ is being kicked by the boy.*
16. polít (sprinkle)	**11061**	**Chlapec polil dívku.** *The boy sprinkled the girl.*	**Chlapec byl polit dívkou.** */ was sprinkled by the girl.*
17. nést (carry)	**225789**	**Kůň nese pána.** *The horse carried the man.*	**Kůň je nesen pánem.** / was carried by the man.
18. uvěznit (imprison)	**14668**	**Drak uvěznil princeznu.** *The dragon imp. the princess .*	**Drak byl uvězněn princeznou.** */ was imprisoned by the princess.*
19. rozzlobit (upset)	**7821**	**Tatínek rozzlobil maminku.** *The father upset the mother.*	**Tatínek byl rozzloben mam.** */ was upset by the mother.*
20. popravit (execute)	**18728**	**Kat popravil zloděje.**	**Kat byl popraven zlodějem.**

(execute)		*The executioner exec. the thief.*	*/ was executed by the thief.*
21. porazit	328407	**Princ porazil draka.**	**Princ byl poražen drakem.**
(defeat)		*Prince defeated the dragon.*	*/ was defeated by the dragon.*
22. pokousat	7498	**Pes pokousal pána.**	**Pes byl pokousán pánem.**
(bite)		*The dog bit the man.*	*/ was bit by the man.*
23. škrtit	6725	**Žena škrtí muže.**	**Žena je škrcena mužem.**
(choke)		*The woman is choking the man.*	*/ is choked by the man.*
24. léčit	78618	**Maminka léčí dceru.**	**Maminka je léčena dcerou.**
(cure)		*The mother is cur. the daughter.*	*/ is being cured by the daughter.*
25. bít	41209	**Chlapec bije dívku.**	**Chlapec je bit dívkou.**
(hit)		*The boy is hitting the girl*	*/ is being hit by the girl.*
26. vážit	115360	**Chlapec váží dívku.**	**Chlapec je vážen dívkou.**
(weight)		*The boy is weighting the girl.*	*/ is baing weighted by the girl.*
27. informovat	444361	Muž informoval policistu.	Muž byl informován policistou.
(inform)		*The man inf. the policeman*	*/ was informed by the policeman.*
28. přinést	443158	Chlapec přinesl dívku.	Chlapec byl přinesen dívkou.
(bring)		*The boy brought the girl.*	*/ was brought by the girl.*
29. vybrat	424384	**Princ si vybral princeznu.**	**Princ byl vybrán princeznou.**
(chose)		The prince chose the princess.	/ was chosen by the princess.
30. zastřelit	56587	**Muž zastřelil ženu.**	**Muž byl zastřelen ženou.**
(shoot)		*The man shot the woman.*	*/ was shot by the woman.*
31. zavřít	413466	**Černokněžník zav. princ.**	**Černokněžník byl zav. princ.**
(lock)		The wizard locked the princess.	/ was locked by the princess.
32. pustit	252277	**Žena pustila zloděje.**	**Žena byla puštěna zlodějem.**
(released)		*The woman released the thief.*	*/ was released by the thief.*
33. vést	1094017	**Chlapec vedl psa.**	**Chlapec byl veden psem.**
(lead)		*The boy led the dog.*	*/ was led by the dog.*
34. objevit	664805	**Dívka objevila chlapce.**	**Dívka byla objevena chlapcem.**
(find)		*The girl found the boy.*	*/ was found by the boy*
35. učit	215199	**Muž učil chlapce.**	**Muž byl učen chlapcem.**
(teach)		*The man thought the boy.*	*/was thought by the boy.*
36. vidět	1249642	**Zloděj viděl policistu.**	**Zloděj byl viděn policistou.**
(see)		*The thief saw the policeman.*	*/ was seen by the policeman.*
37. navštívit	275332	**Dívka navštívila babičku**	**Dívka byla navštívena babičkou.**
(visit)		*The girl visited the grandmother.*	*/ was visited by the granmother.*
38. předehnat	1447	**Chlapec předehnal koně.**	**Chlapec byl předehnán koněm.**
(overtake)		*The boy overtook by the horse.*	*/ was overtaken by the horse.*
39. políbit	15037	**Princ políbil princeznu.**	**Princ byl políben princeznou.**
(kiss)		*The prince kissed the princess.*	*/ was kissed by the princes.*
40. zranit	221246	**Chlapec zranil dívku.**	**Chlapec byl zraněn dívkou.**
(injure)		*The boy injured the girl.*	*/ was injured by the girl.*

Appendix II. Statistical results.

Table 5.3. The t-values and p-values of the eye-tracking results in active and passive condition for both aphasic and control participants.

Group	region	Active		Passive	
		t-value	*p*	*t*-value	*p*
Aphasic	R1	-2.7729	0.01	1.5371	0.09
	R2	-1.4353	0.2	0.50456	0.6
	R3	2.6425	0.03	-0.55866	0.6
Control	R1	-2.9137	0.01	2.3145	0.03
	R2	1.1274	0.3	1.059	0.1
	R3	14.632	> 0.001	8.7252	> 0.001

Table 5.4. The t-values and p-values for the eye-tracking results as a function of behavioral accuracy in active and passive condition for aphasic participants.

Accuracy	region	Active		Passive	
		t-value	*p*	*t*-value	*p*
Correct	R1	-1.7885	0.1	0.52813	0.6
	R2	-1.1946	0.2	1.2444	0.2
	R3	3.0523	0.03	2.5446	0.02
Incorrect	R1	-2.0459	0.04	1.3739	0.2279
	R2	-0.95437	0.1	-0.24699	0.8
	R3	-1.13122	0.3	-10.77	> 0.001

Abstract

Sentence Processing in Agrammatic Aphasia

This thesis introduces the syndrome of agrammatic aphasia with a primary focus on comprehension deficits. The theoretical part defines agrammatic aphasia and describes symptoms related to agrammatism not only across distinct language modalities but also across different languages. Special attention is dedicated to agrammatic symptoms in Czech. Common methodological approaches to the study of agrammatism are listed and evaluated; and the distinct theoretical accounts of comprehension deficits in agrammatism are introduced and critically assessed. The experimental part of the thesis attempts to investigate the processing of active and passive sentences, and the underlying nature of the deficits in agrammatic aphasia related to non-canonical sentence comprehension The experiment employs eye-tracking-while-listening paradigm combined with a sentence-picture matching task to test these selected hypotheses: 1) the Trace Deletion Hypothesis; 2) the Lexical Integration Hypothesis; and 3) the Pathological Slow-Down Hypothesis. The results bring evidence consistent with the Pathological Slow-Down Hypothesis, which explains the comprehension deficits in agrammatism as a pathological slow-down preventing successful syntactic processing. The study thus contributes to the understanding of the causes responsible for the comprehension deficits observed in agrammatic aphasia.

Keywords: agrammatism, agrammatic aphasia, sentence processing, linguistic aphasiology, eye-tracking, on-line methods

Anotace

Zpracování vět u agramatické afázie

Tato práce pojednává o syndromu agramatické afázie, primárně pak o poruchách porozumění s tímto syndrome spojených. Teoretická část definuje agramatickou afázii a popisuje symptomy u agramatické afázie napříč různými jazyky. Zvláštní pozornost je věnována také češtině v agramatismu. Rozdílné experimentální metody, kterými lze tyto symptomy zkoumat jsou představeny společně s jejich klady a zápory. Popsány a kriticky zhodnoceny jsou také vybrané teoretické přístupy k problematice poruchy porozumění u agramatické afázie. Praktická část práce předkládá experiment, který s pomocí on-line a off-line metod studuje příčiny poruch zpracování pasivních vět u českých pacientů trpících agramatickou afázií v porovnání s kontrolní skupinou běžných českých mluvčí. Experiment s využitím eye-trackingu na úloze přiřazování prezentovaných vět k odpovídajícím vizuálním stimulům testuje vybrané hypotézy: a) Hypotézu vymazávání stop, b) Hypotézu porušené lexikální integrace, a c) Hypotézu zpomaleného syntaktického zpracování. Výsledky mluví ve prospěch Hypotézy zpomaleného syntaktického zpracování, která vysvětluje poruchu porozumění u agramatismu jako patologické zpomalení zpracování zabraňující úspěšnému syntaktickému zpracování. Tato studie tak přispívá k pochopení příčin, které vedou k poruchám porozumění u agramatické afázie.

Klíčová slova: agramatismus, agramatická afázie, zpracování vět, lingvistická afaziologie, eye-tracking, on-line metody

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